CHAPTER 5 -- PROPOSED MINIMUM FLOW CRITERIA (RESULTS)

INTRODUCTION

The following chapter describes the basis for establishing the MFL criteria as required in Chapter 373, Florida Statutes for the Loxahatchee River and Estuary. This chapter provides a summary of the scientific approach and technical relationships that were evaluated in defining significant harm for the water body and a detailed presentation of the proposed MFL criteria with supporting documentation.

Once the water resource functions of the river and estuary that need to be protected by the establishment of the MFL were identified (**Chapter 2**) specific technical relationships were developed and evaluated to define significant harm for the water body. The following sources of information were reviewed and considered in the development of these criteria:

1. **Literature Review**: Results of a literature search produced a bibliography containing nearly 100 citations (**Appendix A)** concerning technical relationships among flow, salinity, hydrodynamics and key biological indicator communities and species for the Northwest Fork, the downstream estuary and similar systems. This review involved (a) review of previous studies that identified relationships among river flow, salinity and resource protection; (b) identification of species or biological communities that could potentially be used as indicators, targets, or criteria for determining a minimum flow for the river and the estuary; and (c) determination of how these indicator species or indicator communities have been impacted by historic hydrologic alterations within the watershed.

2. **VEC Approach:** A “Valued Ecosystem Component” (VEC) approach similar to that developed by the EPA (1987) was developed to establish a minimum flow regime that will protect important components of the river ecosystem from significant harm.

3. **Historical Flow and Salinity Data**: Review of available USGS and SFWMD flow data and stage records was conducted using the DBHydro database for the Lainhart Dam, Cypress Creek, Hobe Grove Ditch, and Kitching Creek. These data were analyzed in terms of descriptive statistics, and reviewed for trends (**Appendix D**). Historical salinity data provided by the Loxahatchee Environmental Control District for four sites along the river were also reviewed. The long-term flow records and collected salinity database were used as input to a hydrodynamic salinity model developed for the river and estuary (**Appendix E**).

4. **Aerial Photography/GIS studies**: Review and interpretation of historical black and white aerial photographs from 1940, 1953, 1964 and color infrared photos from 1979, 1985 and 1995 were used to quantify and document changes over time in the distribution

of the dominant plant communities that comprised the floodplain swamp, wetlands and uplands located along the river corridor **(Appendix B)**.

5. **River Vegetation Survey**: Two vegetation surveys were conducted along the NW Fork of the river to characterize the species and community changes that occur along the salinity gradient upstream from the Jupiter Inlet. These surveys provided both community-based (i.e., canopy structure analysis, total number of observed species, community composition) and species-based (i.e., abundance, number of individuals, height, trunk diameter, age class) information which was used to examine relationships between salinity conditions and vegetation, as well as to construct a model that relates long-term salinity conditions with current vegetation community parameters **(Appendix C)**.

6. **Soil Salinity Samples.** District staff collected soil samples along the Northwest Fork in January 2002 to investigate soil salinity concentrations and provide a basis for future sampling projects. Four transects were established across the river floodplain, at sites representing different degrees of salinity exposure from tidal flux, and extended from the riverbank to the edge of the upland-floodplain ecotone **(Appendix G)**.

7. **Hydrodynamic/Salinity Model**: A two-dimensional depth-averaged finite element hydrodynamic/salinity model (RMA-2 and RMA-4 codes) was used to generate a long-term simulated mean daily salinity times series for each river vegetation sampling site. Descriptive statistics (mean, standard deviation, median, mode, maximum) were calculated to describe the salinity regime for each site and analyzed in terms relevant to the river's vegetation community (i.e., calculation of salinity magnitude, duration of each event, and the period of time between events). A database was developed for each of the seven sites relating measured vegetation community parameters with data derived from the simulated 30-year salinity record **(Appendix E)**.

8. **Vegetation/Salinity Model:** Where highly correlated relationships were found between measured vegetation parameters and modeled long-term salinity conditions, formulas were developed to describe these relationships and a deterministic regression model was constructed to predict (extrapolate) long-term vegetation community response to salinity. A vegetation/salinity model was developed and used to determine salinity conditions and flows associated with plant community parameters.

9. **Consumptive Use Permit Analyses:** The overall effect of consumptive uses (public water supply, agriculture, and self-supplied residential wells) on providing flows to the Northwest Fork of the Loxahatchee River was also investigated. SFWMD staff reviewed and analyzed data from permit applications and conducted groundwater model simulations to estimate the relative effect of consumptive uses on water levels in the Loxahatchee Slough and deliveries to the Northwest Fork of the Loxahatchee River during wet, normal and dry periods **(Appendices I & O)**.

RESULTS OF LITERATURE REVIEW

One requirement for developing minimum flow and level criteria is to use "best available information". The Loxahatchee River has been the focus of numerous studies over the past three decades. A literature review was conducted to review the results of these studies as they may relate to defining a flow/salinity relationship or recommended minimum flow for the Loxahatchee River. Results of the literature review as well as an accompanying bibliography of these studies are provided in **Appendix A** of this report**.** The literature review is organized chronologically beginning in the early 1970s when the problem of saltwater intrusion in the Northwest Fork was first identified in the scientific literature as a major public concern. Major findings derived from this review are summarized below.

1. The Loxahatchee River and estuary is a small (544 km^2) shallow-water body in southeastern Florida that empties into the Atlantic ocean at the Jupiter Inlet. Historical evidence indicates that the inlet periodically opened and closed to the sea as a result of natural events. Originally, freshwater and tidal flows kept the inlet open for some of the time. Near the turn of the century, some flow was diverted by construction of the Intracoastal Waterway and the Lake Worth Inlet and by modification of the St. Lucie Inlet. Subsequently the Jupiter Inlet remained closed for much of the time until 1947. Since 1947, the inlet has been permanently open (Wanless et al. 1984).

2. Fresh water enters the NW Fork of the Loxahatchee River primarily through four major tributaries. Flows received from the Loxahatchee Slough and G-92, on average, represent approximately 57% of the total flow (as measured at SR 706) delivered to the NW Fork, while Cypress Creek contributes another 32%, Hobe Grove Ditch 7% and Kitching Creek, 4% (Russell and McPherson, 1984). These proportions vary considerably in response to seasonal and local rainfall conditions. See also **Table 23** of this Report.

3. In the early 1970's it was recognized that hydrologic alterations of the watershed have reduced freshwater flow delivered to the river causing the upstream movement of saltwater during dry periods as well as saltwater intrusion of the local ground water aquifer (Land et al. 1972, Rodis 1973, Birnhak 1974). The primary cause of observed changes in flora and fauna along the NW Fork of the River was identified as the upstream movement of saltwater during drought periods (Rodis 1973, Birnhak 1974, Alexander and Crook 1975, FDNR 1985, Duever and McCollum, 1982). These studies recommended that to maintain and protect the natural communities of the Northwest Fork, sufficient freshwater should be redirected from inland canals and water storage areas to the Loxahatchee River.

4. Rodis (1973) recommended that a constant freshwater flow of 50 cfs delivered over the Lainhart Dam would be required to restrict the upstream movement of saltwater and preserve remaining natural communities in the middle and upper reaches of the NW Fork. This recommendation included an assumption that other contributing tributaries (Cypress Creek, Hobe Grove Ditch and Kitching Creek) would provide an additional 80 cfs.

5. Birnhak (1974) suggested that flows of about 60 cfs from Lainhart Dam to the Northwest Fork would keep saltwater intrusion below Station 5 near Kitching Creek (river mile 8).

6. Alexander and Crook (1975) produced a comprehensive study of the major changes in vegetation that have occurred in South Florida over the last 30 or more years. One of their study plots included an area of the Northwest Fork near the mouth of Kitching Creek. Based on photo-interpretation of aerial black and white photos taken from 1940 and 1970 they concluded that since 1940, wet prairie and cypress swamp hardwoods had lost ground to pineland and mangrove communities due to a lowering of the groundwater table and invasion of saltwater between river miles 6 and 8.

7. Each of these studies identified the presence of a freshwater layer of water overlying denser seawater within the estuary and portions of the Northwest Fork. This vertical stratification of the water column, or saltwater wedge, is a common feature of estuaries. The upstream tip of the saltwater wedge is characterized as a bottom salinity that exceeds 2 parts per thousand (Russell and McPherson 1984, Mote Marine Lab, 1990b) as shown in the conceptual diagram below (**Figure 18**). Salinity studies conducted within the river (Russell and McPherson, 1984) indicate the average distance of the salinity wedge between top and bottom is approximately 0.5 miles (**Figure 18**). During periods of reduced freshwater input, the saltwater wedge may extend as far as 5 to 10 miles upstream of the Northwest Fork. The saltwater wedge was reported to move daily from 0.5 to 1.5 miles up and down the river in response to freshwater inflow and daily tidal fluctuations (Russell and McPherson, 1984).

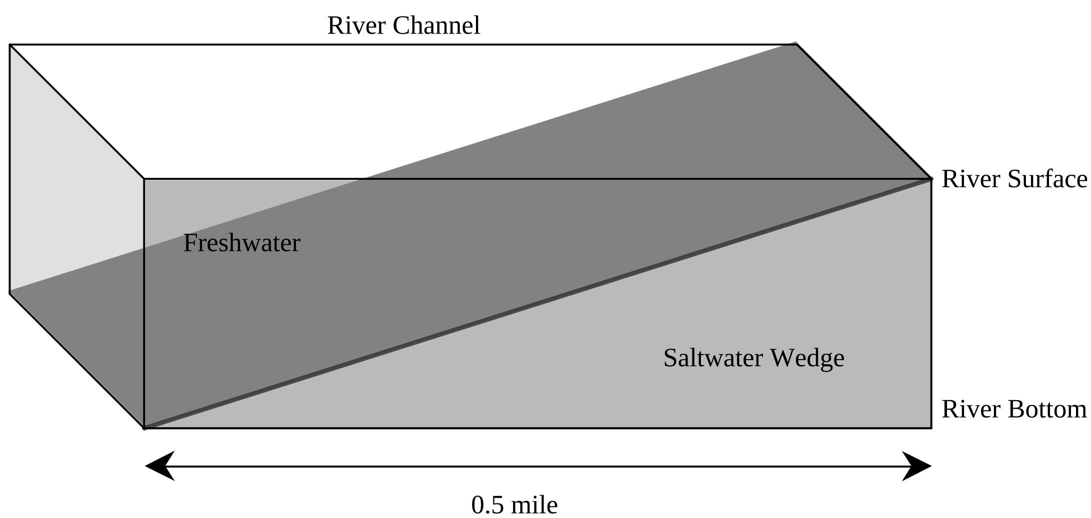


Figure 18. Conceptual diagram of the saltwater wedge.

8. Russell and McPherson (1984) conducted an intensive study of the relationship of salinity distribution and freshwater inflow in the Loxahatchee River estuary from 1980-1982. Freshwater inflows to the major tributaries were measured at six continuous gauging stations including the Northwest Fork, Cypress Creek, Hobe Grove Ditch, and Kitching Creek. Key results of this study showed that the total amount of freshwater [from all sources] needed to restrict brackish water (>2 ppt) from the upstream reaches of the Northwest Fork at mean high tide were estimated to be as shown in **Table 22.**

Table 22. Total mean daily discharges to the Northwest Fork and corresponding upstream extent of the saltwater wedge in river miles (from: Russell and McPherson 1984)

Total* Mean Daily Freshwater Discharge (cfs)	Upstream extent of saltwater wedge in river miles
220	7.0
130	8.0
120	8.2
75	9.0
43	10.0
26	11.0

* Includes NW Fork + all upstream tributaries

Figure F-4, Appendix F provides a summary of salinity profiles (at high tide) developed by Russell and McPherson (1984) for the Northwest Fork under various flow discharge rates. Russell and McPherson (1984) also noted that maintaining the above flow regime would not protect the river under all conditions. During extreme high tides and storm events, saltwater could still move upstream for brief periods. Based on the flow/salinity relationships provided above, the total amount of freshwater (from all sources) needed to restrict the saltwater wedge from the upstream reaches of the river was determined to be 120 cfs at river mile 8.2, for example, which is located upstream of the confluence of Kitching Creek and the Northwest. Of this total flow, 57% (or about 68 cfs) is derived from the Northwest Fork, 32% (38 cfs) from Cypress Creek, 7% (8 cfs) from Hobe Grove Ditch, and 4% (5 cfs) from Kitching Creek.

9. Law Environmental (1991a) summarized unpublished SFWMD flow, salinity and rainfall data collected from 18 sites within the Northwest Fork and downstream estuary from 1985-1988. Average and median flows discharged to the Northwest Fork of the river through G-92 were recorded as 50 and 56 cfs, respectively over the 3-year study. Average bottom salinity recorded at river miles 9.2, 8.0, 6.9, and 5.7 were 0.4, 2, 8, and 17 ppt, respectively. Vertical stratification of the water column was most prominent at river miles 2.6 and 8.0. Under extreme low flow conditions the salinity wedge was transported upstream by slightly more than one river mile. Under these low flow conditions, average bottom salinity recorded at river miles 9.2, 8.0, 6.9, and 5.7 were 3, 13, 17, and 25 ppt. Surface and bottom salinity at river mile 8, located within the area of cypress die-off, was less than 0.2 ppt and 0.4 ppt for 50% of the 1985-1988 data set. Discharges from S-46 were reported to have substantial effects upon salinity regimes many miles upstream of the Northwest Fork. The report concluded that salinity control by a regulated freshwater discharge at average flow conditions of 40 to 50 cfs could benefit the ecosystem by establishing a stable salinity wedge location for the estuary system.

10. McPherson and Halley (1996) in their publication, *The South Florida Environment: A Region Under Stress,* documented the encroachment of mangroves, along with the overall reductions in freshwater flows, maintenance of lower groundwater levels, short duration high volume freshwater flows for flood protection, and changes in the quality of runoff.

11. More recent studies conducted by Dent and Ridler (1997) indicate that flows delivered to the Northwest Fork (as measured at SR 706) that are equal or below 50 cfs, may not be sufficient to maintain freshwater conditions (less than 2 ppt) as far downstream as river mile 8. Their data indicated that over a one-year monitoring period, the 50 cfs target was met only 33% of

the time. When flow was equal to or less than 50 cfs, bottom salinity exceeded 2 ppt upstream of water quality monitoring station 65 (river mile 8.6) 95% of the time while station 64 (river mile 7.7) exceeded 2 ppt 100% of the time. This report recommended a minimum flow rate of 75 cfs (as measured at SR 706 bridge) for the end of the dry season (May) and 130 cfs for the wet season (July-November). They also suggested a maximum flow range, i.e., discharges should not exceed 150 cfs during the months of February-May, and no greater than 300 cfs during the wet season (June-November).

12. Dent and Ridler (1997) also provide information as to the sensitivity in which salinity concentrations within the river react to changes in flow. For example at water quality station 65 (river mile 8.6), a drop in the upstream flow rate from 150 cfs to below 60 cfs over a five day period resulted in the almost immediate movement of salt water into the area.
13. Salinity studies were also conducted by the Loxahatchee River Environmental Control District to determine the effects that physical modifications to the river and estuary, such as filling man-made gaps between the winding oxbows in the Northwest Fork had on salinity conditions in the river. Analyses of salinity data collected before and after the barriers were installed indicate that by redirecting the flow of the river through the original meandering oxbows of the river, approximately 0.7 river mile were restored to the distance needed for saline tidal waters to move upstream. These modifications resulted in a decline in salinity levels upstream of the gaps (Dent 1997b).
14. As late as 2000, the original USGS flow target of 50 cfs established by Rodis (1973) was still identified as the recommended minimum flow target for the Northwest Fork (FDEP & SFMWD, 2000). However, a 1994 study that was presented to the Loxahatchee River Management Coordinating Council determined that flows of 50 cfs were insufficient to meet the stated goals for the River (Dent, unpublished). The origin of this target was based on water flowing over the Lainhart dam; a broad crested weir located 0.1 mile north of SR 706. Previous flow rating curves developed for the dam in 1984 tended to under estimate flow over the dam. The dam was reconstructed in 1998 and flow-rating curves developed for the dam tended to significantly over estimate discharge. For this reason District staff conducted a re-calibration of the rating curve for the Lainhart dam in 1998. Re-calibration of the dam and subsequent statistical review of this new flow/salinity information resulted in the recommendation that a minimum flow target of 64 cfs was needed to maintain the saltwater wedge (as 2 ppt bottom salinity) just downstream of the confluence of Kitching Creek and the Northwest Fork of the river (SFWMD 1999). Details of the re-calibration procedure and a summary of the statistical results are provided in **Appendix D** of this report.
15. Several studies also recommended consideration of the construction of a saltwater barrier to reduce the upstream movement of saltwater during dry periods.

Based on results of the literature review, a number of flow levels have been proposed for the Northwest Fork of the Loxahatchee River during the past 30 years, ranging from a constant flow of 50 cfs to recommended dry and wet season flows of 75-130 cfs. Although these studies have produced valuable information concerning river flow and salinity relationships, none were developed based on the specific statutory minimum flows and levels requirements of Chapter 373.042(1) F.S. i.e. flow conditions that would need to be maintained to prevent significant harm to the resource.

HYDROLOGIC AND SALINITY CONDITIONS

Sources of Freshwater Inflow

Northwest Fork

Table 23 provides a summary of average freshwater flows delivered to the three forks of the Loxahatchee estuary during the wet and dry season as well as during selected drought events. Four major sources of water (G-92 and the Lainhart Dam, Cypress Creek, Hobe Grove Ditch and Kitching Creek) provide the majority of freshwater flow to the Northwest Fork of the Loxahatchee River. Other historical inputs such as Moonshine Creek and Wilson Creek have been highly altered by drainage and development and today provide only a very small portion of flow to the Northwest Fork and are not included in **Table 23.** Of these four sources, the Lainhart Dam (the main stem of the river) is the largest contributor, providing between 51 and 56 percent of the flow to the Northwest Fork during the wet and dry seasons.

Table 23. Summary of Average Wet and Dry Season Flows to the Loxahatchee Estuary.

	Average Daily Flow (cfs)		1980-81 drought Avg. flow (cfs)		1989-90 drought Avg. Flow (cfs)		
Tributary	**Wet Season**	**Dry Season[1]**	**Wet Season**	**Dry Season**	**Wet Season**	**Dry Season**	**Period of Record**
Northwest Fork							
Lainhart Dam	95	70	65	35	68	26	1971-2001
Cypress Creek	60	32	57	30	41	30	1980-1991
Hobe Grove Ditch	9	7	11	7	9	7	1979-1991
Kitching Creek	21	16	8	5	3	1	1979-2001
Subtotal	*185*	*125*	*141*	*77*	*121*	*64*	
North Fork[2]							
USGS sites 28B & 28c	4	1	4	1	ND	ND	1980-1982
Southwest Fork							
C-18 Canal@S-46	94	61	61	20	8	8	1961-2001
Total	283	187	206	98	129	72	

[1] Wet season defined as May 15- Oct. 15; Dry season = Oct. 16- May 14
[2]From Russell and McPherson 1984 (POR 1980-1982)

* The average wet and dry season flows calculated for each tributary were based on the available data in each tributary's individual period of record, and were not restricted to the dates in which flow values were concurrently available for all four tributaries.

The second largest contributor is Cypress Creek representing 26 – 32 percent of the total flow delivered to the Northwest Fork, followed by Kitching Creek (11-13%) and Hobe Grove Ditch (5%). In terms of average dry season flows, the Lainhart Dam provides about 70 cfs, Cypress Creek, 32 cfs; Kitching Creek, 16 cfs; and Hobe Grove Ditch, 7 cfs for an average total of 125 cfs of freshwater delivered from the Northwest Fork to the Loxahatchee estuary (**Table 23**). These dry season flows were reduced by more than one-half during 1980-1981 and 1989-90 drought periods with average values ranging between 26-35 cfs for the Lainhart Dam, Cypress Creek (30 cfs), Hobe Grove Ditch (7 cfs) and Kitching Creek (1- 5 cfs) for an average total of only 64 -77 cfs of flow discharged to the estuary during low rainfall periods (**Table 23**).

Review of historical flow records for the Lainhart Dam data over the past 30 years shows that flows delivered to the Northwest Fork have significantly increased since 1990 **(Figure 19**).

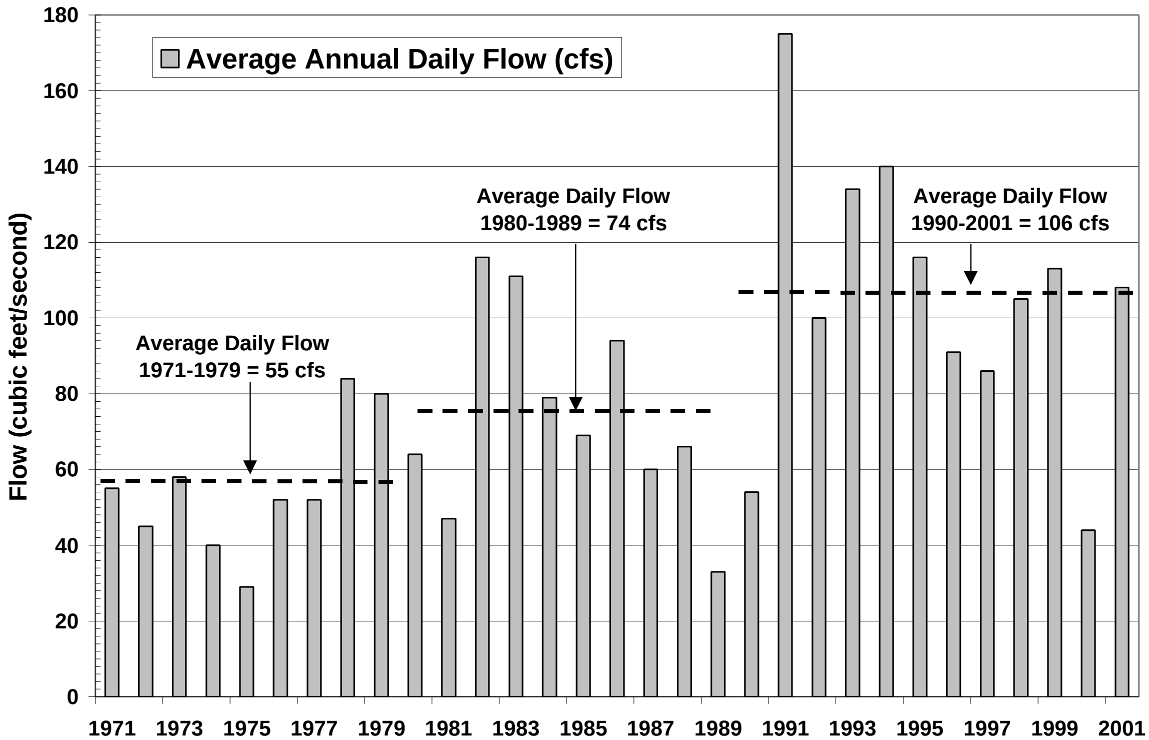


Figure 19. Average Annual Daily Flows (cfs) recorded for the Lainhart Dam (1971-2001).

The purpose of this analysis was to represent decadal differences in freshwater flow patterns, i.e. to compare flow conditions in the 1970's with the 1980's and 1990's. Data from the 1970's and 1980's were considered to be "historical" and data from the 1990's represent more "current" conditions. Average annual daily flows delivered to the Northwest Fork during the 1970's and 1980's ranged between 55 and 74 cfs. These flows increased dramatically during the 1990's reaching an average of 106 cfs due to several factors. First, the 1990's represent a period of increased rainfall within the region (**see Figure 4,** Chapter 2). Increased rainfall experienced within the basin coupled with operational improvements (enlarged culverts and an automated gate) made to the upstream G-92 structure in 1987 most likely played a key role in the District's ability to provide increased flow to the Northwest Fork of the river over the past 12 years.

Table 24 indicates how the distribution of flows has changed at different flow rate thresholds. In general the percentage of time that flows to the river were less than 65, 50, 35 and 25 cfs have decreased. Over the past decade, the 65-cfs flow target for the Lainhart Dam, as proposed in the Northern Palm Beach County Comprehensive Water Management Plan (SFWMD, 2002), is met about 57% of the time. Even though a number of hydrological improvements have been made within the basin over the last decade, there are still periods of time when the river receives very little flow. The occurrence of flow rates less than 10 cfs increased slightly from 6% to 7% during the last 12 years (**Table 24**). During that period, flows less than 35 cfs occurred 73 times with an average duration of 15 days and a return frequency of

2 months. It can be inferred, therefore, that exceedances of the proposed MFL occurred, on average, several times per year and significant harm is continuing to occur to the resource.

Table 24. Comparison of historical and more current flow conditions at the Lainhart Dam (Northwest Fork of the Loxahatchee River) based on USGS data from 1971 to 2000.

Flow Target	Historical (1971-1989)*				Current (1990-2001)**			
	% of time below desired flow rate	No. of Events	Avg. Duration (days)	Return Frequency (months)	% of time below desired flow rate	No. of Events	Avg. Duration (days)	Return Frequency (months)
65 cfs	58 %	124	32	1.8 months	43 %	113	17	1.3 months
50 cfs	47 %	113	29	2 months	36 %	101	15	1.4 months
35 cfs	34 %	94	24	2.4 months	25 %	73	15	2 months
20 cfs	16 %	59	19	3. 8 months	15 %	35	18	4 months
10 cfs	6 %	26	16	8.6 months	7 %	16	19	8.8 months

* =18.75 year period of record, ** =11.8 year period of record

Presently, G-92 is the only structure that can be controlled by the District through remote telemetry to release water from the Loxahatchee Slough and C-18 canal to the Lainhart Dam and the Northwest Fork of the river. The other three tributaries do not have controllable structures. For the most part, flows from these structures are primarily rain-driven. Surface water flows from G-92 combine with surface water runoff from the Jupiter Farms area and SIRWCD C-14 canal to convey water to the Lainhart Dam, the primary source of freshwater for the Northwest Fork. A time series of historical flow data (1971-2001) for the Lainhart Dam is provided in **Appendix D**. These data are summarized in the flow duration curve presented in **Figure 20** for the 30 year

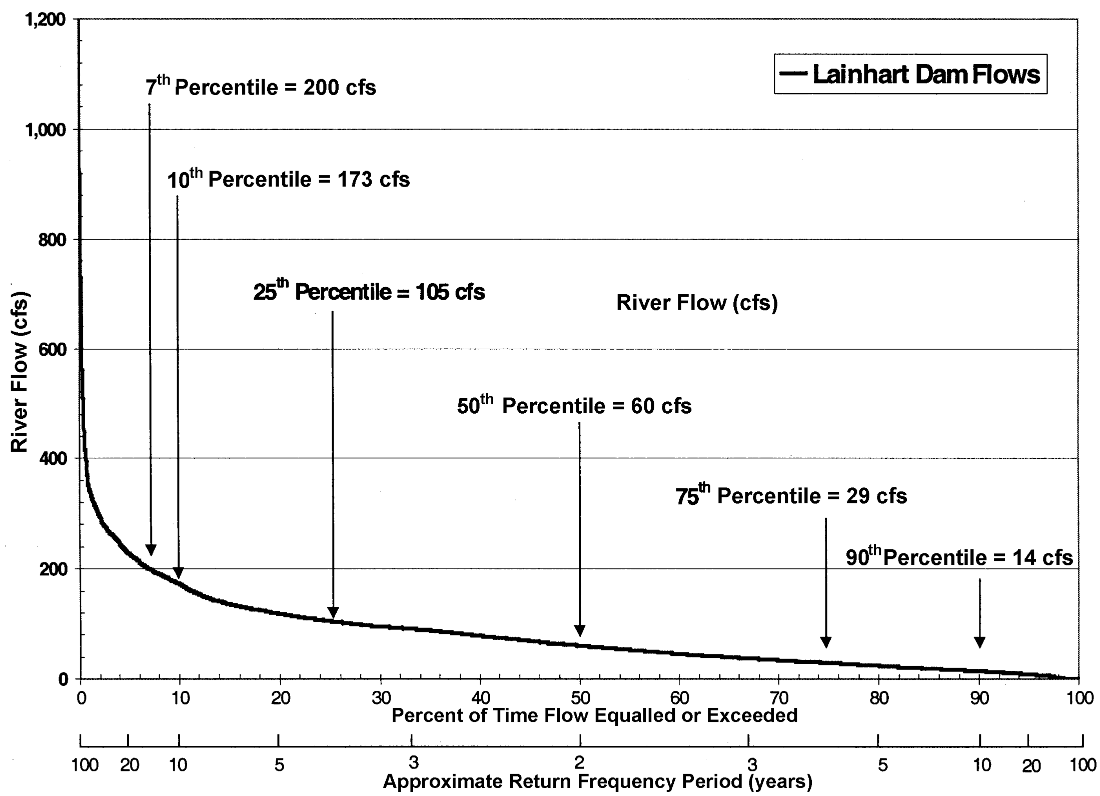


Figure 20. Flow Duration Curve for the Lainhart Dam (1971-2001)

period of record. The median (50th percentile) flow value for the Lainhart Dam is 60 cfs, while the 90th, 75th, 25th and 10th percentiles are 14, 29, 105 and 173 cfs, respectively.

Figure 20 shows that Lainhart Dam flows fall to less than 15 cfs approximately once every 10 years (90^{th} percentile). Under very low flow conditions (<10 cfs) saltwater has been recorded to extend upstream to Trapper Nelson's (river mile 10.7) and river bottom salinities were as high as 7 ppt (Russell and McPherson 1984). These low flow periods have the potential to stress or temporarily eliminate populations of freshwater fish or aquatic invertebrates downstream of Trapper Nelson's when exposed to saline conditions. Low flow events such as these also restrict recreational use of the Wild and Scenic portion of river by canoe and kayak.

North Fork

The North Fork is a shallow tributary that currently contributes only a small percentage of the total freshwater flow to the estuary (Russell and McPherson 1984; Sonntag and McPherson 1984). Brackish conditions extend approximately 5.0 miles up this branch from the mouth of the inlet (McPherson and Sabanskas 1980). The North Fork of the estuary has an average depth of 3.4 feet, maximum depth of 6.6 feet, average width of about 0.15 miles and covers a total area of about 200 acres. Freshwater flow to the North Fork is uncontrolled. A study by Russell and McPherson (1984) indicated that freshwater flow from the North Fork represented only about 2% of total freshwater flow to the estuary **(Table 23)**. Much of the upper end of the watershed of the river lies within Jonathan Dickinson State Park. The shoreline along the lower estuary is surrounded by residential development and is mostly bulkheaded. The sediments generally consist of fine sand and mud. Some areas have deep pockets of soft mud that has a high content of organic material. Water quality is often poor due to high levels of turbidity and color that limit light penetration, low levels of dissolved oxygen and occasional high concentrations of fecal coliform bacteria (Dent et al. 1998). Due to the low input of fresh water, bottom salinities in the lower section of the North Fork are usually above 25 ppt, while salinities further upriver average about 14 ppt.

Southwest Fork

Under normal operating conditions discharges are made to the Southwest Fork of the estuary through the S-46 structure when stages in the C-18 canal exceed 15.0 ft. NGVD. However during a major storm event these gates are operated manually to quickly lower water levels in the canal for flood control and can maintain a headwater between 13 and 14 ft. NGVD for a short period of time. As a result, flows delivered from S-46 to the estuary are highly variable in response to upstream water management (**Figure 21**). Review of flow data collected from S-46 for the period of record 1990-2000 shows that although average flows delivered to the estuary ranged between 61 and 94 cfs for the wet and dry seasons (**Table 23**) the median value was zero. No discharges were made to the estuary for 67% of the time over the period of record. In contrast, during 1995 and 1999 were there were periods when mean daily flows exceeded 2,500 cfs in response to major storm events experienced within the watershed (**Figure 21).** Events such as these are thought to have a major impact on the both water quality and the salinity in estuary.

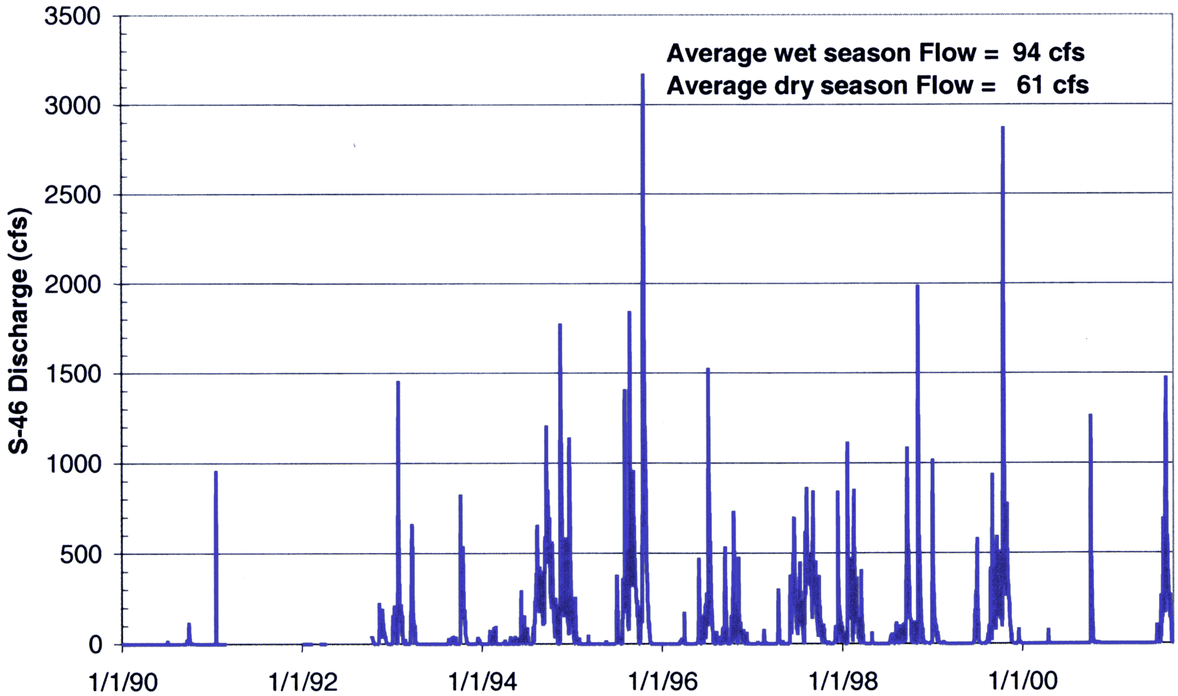


Figure 21. Water Management Releases from the C-18 canal via S-46 (1990-2001)

Salinity Conditions within the Northwest Fork

Historical Data

The following information was summarized from water quality monitoring studies conducted by the Loxahatchee River Environmental Control District (Dent 2002, personal communication). The database includes information periodically collected from 1970 up to 2001. For the following analysis, water quality monitoring sites were grouped into segments defining different salinity zones, or habitats, found within the estuary and River. These include the marine and coastal zone, estuary, wild & scenic segment, and freshwater tributaries. Measured salinity data for these river segments are presented in **Table 25**.

The marine/coastal segment of the river includes the habitat that is near the mouth of the Jupiter Inlet. Average salinity values range from 27.7 to 30.7 ppt for the period of record (1970-2001). Average salinity values for this segment are not significantly different for the two 12-year periods between 1970 and 1993, for the more recent above average rainfall years (1994-1997) or drought years (1998-2001) (**Table 25**). These data indicate that tidal flux, rather than freshwater inflow from upstream, is the primary factor influencing salinity concentrations at this location.

The Loxahatchee River estuary lies in the mixing zones between upstream freshwater inflows delivered by the Northwest Fork and Southwest Fork (C-18 canal) and tidal salinity provided by the Jupiter inlet. Average salinity measured in the estuary from 1970 through 1993 was between 21 and 22 ppt. As expected, the average measured salinity was lower (19.6) during above-average rainfall years (1994-1997) and slightly higher (23.0) in drought years (1998-

Table 25. Measured salinity from the NW Fork of the Loxahatchee River.*

River Segment	Period	Comments	Mean Salinity (ppt)
Marine/Coastal	1970-1981	12-year period	27.7
	1982-1993	12-year period	29.0
	1994-1997	Above-average rainfall years	30.7
	1998-2001	Drought years	30.6
Estuarine	1970-1981	12-year period	22.0
	1982-1993	12-year period	21.2
	1994-1997	Above-average rainfall years	19.6
	1998-2001	Drought years	23.0
Wild & Scenic	1970-1981	12-year period	0.3
	1982-1993	12-year period	0.4
	1994-1997	Above-average rainfall years	0.9
	1998-2001	Drought years	2.5
Freshwater Tributaries	1970-1981	12-year period	0.3
	1982-1993	12-year period	0.4
	1994-1997	Above-average rainfall years	0.4
	1998-2001	Drought years	0.7

*Source: Riverkeeper data from the Loxahatchee River Environmental Control District (Dent 2002, pers. comm.)

2001), reflecting increased and reduced freshwater inputs to the estuary, respectively. These data indicate that for this area, long-term salinity values are only somewhat affected (+/-2 ppt) by annual rainfall variation in upstream basins. The primary factor influencing salinity at this location is tidal flux.

Average salinity values for the Wild & Scenic segments of the river (above river mile 6.5) range from 0.3 to 0.4 ppt during the two 12-year periods between 1970 and 1993. After 1993, salinity in this upstream segment increased in both above-average rainfall years (1994-1997, average salinity 0.9 ppt) and during drought years (1998-2001, average salinity 2.5 ppt). These data suggest that upstream portions the river may have experienced high salinities during the past decade. However, the trend is uncertain because the official Wild and Scenic portion of the river includes at least one station (no. 63) that is estuarine rather than fresh water in character.

Freshwater tributaries are those creeks, streams, and canals that are direct sources of freshwater input to the Northwest Fork. These include Kitching Creek, Hobe Groves Ditch, and Cypress Creek. Average salinity values from these tributaries are comparable to those of the Wild & Scenic (freshwater) segment of the River, with values near 0.3-0.4 ppt for both 12-year periods (1970 through 1993) and the more recent above-rainfall years (1994-1997). As expected, salinity was slightly higher during drought years (1998-2001, average salinity 0.7 ppt) as compared to other time periods but was still below 1 ppt.

Soil Salinity Survey Results

Soil sampling was conducted along the Northwest Fork to investigate soil salinity concentration changes along the river and to serve as a reconnaissance effort to gain information upon which to base future sampling efforts. This analysis was also suggested by the scientific peer review panel that reviewed the 2001 Draft Technical Document. Four transects were established along the Northwest Fork in January of 2002. These four transects represented different river vegetation communities and degree of exposure to salinity from tidal influences.

Location of these four transects are shown in **Figure 16.** **Appendix G** provides a description of the methods used to collect samples and analyze data.

Results of these analyses are shown in **Table 26**. Salinity values determined by measuring conductivity were similar to, but slightly above, the results and trends obtained from chloride analyses. Chloride proved to be a more sensitive measure of differences between sites. It should be noted that many natural waters in Florida have background conductivities ranging from 700 to 1000 µmhos/cm. The lowest surface soil (0-0.33 m. depth) chloride concentrations were found at transect 1 (20–29 mg/L), located near river mile 11.5, the site least impacted by tidal salinity intrusion. Progressively higher chloride concentrations were detected in surface soils from transect 2 (49–95 mg/L near river mile 10.5), transect 3 (67–130 mg/L near river mile 9.9), and transect 4 (2000–3000 mg/L near river mile 6.5). At transect 4, chloride levels also varied within the vertical soil profile near the floodplain/upland ecotone and the river bank.

Table 26. Soil Salinity from Transects, Calculated from Conductivity (Cond., ppt*) and Chloride (Cl, ppt) Analyses.

Collection Date	Tran-sect	Appox. River mile	Plot	Conductivity (µho/cm)	Temp. (°C)	Salinity (Cond., ppt)	Chloride (mg/L)	Salinity (Cl, ppt)
1/22/02	1	11.5	River bed (grab)				29	0.05
1/23/02	1		River bottom	760	23		20	0.03
1/23/02	2	10.5	0-3 m	730	24	0.2	95	0.2
1/23/02	2		3-13 m	630	23	0.2	49	0.1
1/23/02	2		33-43 m	680	23	0.2	69	0.1
1/24/02	3	9.9	0-10 m	710	24	0.2	110	0.2
1/24/02	3		30-40 m	870	23	0.5	130	0.2
1/24/02	3		64-74 m				67	0.1
1/24/02	3		Floodplain/upland ecotone	680	23	0.2	81	0.1
1/24/02	4	6.5	0-10 m (0'-1')	9900	24	5.5	3000	4.9
1/24/02	4		0-10 m (1'-2')	7900	25	4	2500	4.2
1/24/02	4		0-10 m (2'-3')	6000	23	4.5	2000	3.3
1/24/02	4		45-55 m (0'-1')	6600	23	4.5	2000	3.4
1/24/02	4		45-55 m (1'-2')	6600	23	4.5	2100	3.5
1/24/02	4		45-55 m (2'-3')	5500	23	3.0	1900	3.2
1/24/02	4		95-105 m (0'-1')	8100	23	6.5	3000	4.9
1/24/02	4		95-105 m (1'-2')	7700	23	4.2	2400	4.0
1/24/02	4		95-105 m (2'-3')	9300	23	5.2	2700	4.5
1/24/02	4		155-165 m (0'-1')	10400	23	5.9	2800	4.7
1/24/02	4		155-165 m (1'-2')	8200	23	6.5	3000	4.9
1/24/02	4		155-165 m (2'-3')	9900	23	7.7	3500	5.7

*ppt = parts per thousand

Soil salinity concentrations did not reveal a well-defined gradient along the River, as was found with the chloride data. Although the plant community at transect 3 contained both freshwater and saltwater-tolerant species, soil salinities were comparable to those at unimpacted sites (transects 1 and 2). However, chloride concentrations at transect 3 (67-130 mg/L), where some red mangrove were present, were higher than in areas inhabited by strictly freshwater vegetation. These data indicate that soil chloride concentration, rather than salinity, may be a better parameter to use to characterize the salinity gradient along upstream portions of the Northwest Fork. A distinct chloride gradient was detected, associated with proximity to the

Jupiter Inlet. However, elevated salinity levels were found only at transect 4 sampling sites, an area that has been impacted by elevated salinity levels for many decades.

Results from this study indicate that “background” salinity levels are very low (0.1-0.2 ppt) in unimpacted areas. This study also suggests that salinity is not retained in the soils for long periods of time. At transect 3, an area was affected by elevated salinity conditions during the most recent drought (1999-2001), salinity was comparable to the pristine transects 1 and 2.

It is important to understand that the scope of this sampling effort was narrow and interpretation or application of the results are limited. This preliminary study does not address potential changes in soil salinity attributed to seasonal hydrological patterns (dry season vs. wet season), droughts, duration of exposure to a salinity concentration, salinity memory (ability to retain sodium or chloride), spatial distribution along the river corridor, and vertical distribution within the soil profile (which affects shallow or deeply rooted plants differently). Results of this study can be useful to design a more comprehensive soil salinity sampling effort.

The results of this reconnaissance investigation were inconclusive. District staff had speculated that (1) soil salinity levels might serve as a reasonable indicator of past salinity conditions within the river that could be linked to the species composition of river vegetation communities, and (2) these results would show a salinity gradient from downstream to upstream areas. Even though this survey was conducted following one of the most extensive droughts recorded in South Florida, results of the survey showed no clear trend and suggest that soil salinity levels may be highly transitory in response to river flow. Based on these results, soil salinity levels may not be a good long-term indicator of stress to river plant communities.

EFFECTS OF CONSUMPTIVE USES

Two analyses were conducted to quantify the relative effects of consumptive use on surface water and ground water flows to the Loxahatchee Slough and Northwest Fork as follows:

a. A search was conducted of the District Water Use Division’s geographical data base to identify all permits, wells and pumps located in the Loxahatchee watershed boundary as well as a buffer area located one-mile outside of the boundary. Results of the data base search are provided in **Appendix O,** listing the major water uses: public water suppliers (PWS), commercial and industrial (IND), golf courses (GOL), landscape irrigation (LAN) and agricultural (AGR) in the watershed and their permitted allocations.

b. In addition, District staff conducted a hydrologic analysis, using output from the Northern Palm Beach County Comprehensive Water Management Plan hydrologic model (MODFLOW), to evaluate the effects of consumptive uses within the basin on the ability to provide flows to the Loxahatchee Slough and River. These results are presented in **Appendix I.**

Based on consideration of the results of these studies and further investigation by the Water Use Division staff, the following summary of impacts was prepared:

Effects of Water Uses on Flows in the Loxahatchee River:

Based on the hydrologic and geologic characteristics of the watershed, not all water uses impact the flows in the Loxahatchee River. Uses of water that have the potential to influence Loxahatchee River flows are identified as follows:

- Direct surface water withdrawals from the River or tributaries
- Direct surface water withdrawals from the C-18 canal upstream of G-92 and S-46
- Groundwater withdrawals that lower the groundwater table under the river, its tributaries or the C-18 canal.

Review of the water use permits issued within the watershed with regard to the above criteria reveals the following:

- No water use permits have been issued that authorize surface water withdrawals directly from the River
- Three water use permits exist that authorize surface water withdrawals directly from the C-18 canal upstream of G-92 and S-46. No water use permits have been issued that authorize surface water withdrawals directly from Hobe Ditch, Cypress Creek or Kitching Creek
- Two permits exist that authorize groundwater drawdowns greater than 0.1 ft beneath the Loxahatchee River or its tributaries
- Four permits exist that authorize groundwater drawdowns greater than 0.1 ft beneath the C-18 canal.

Locations of these projects are shown in **Figure 22.** The dots represent individual wells. Permits typically are issued to landowners or utilities that operate a number of wells on their property. Thus a single permit may be represented by a cluster of dots in close proximity on the map. Impacts are evaluated for each permit and thus consider the combined effects of withdrawals that occur from all of the wells covered by the permit.

The remaining question is, how much do these nine projects affect the flow in the Loxahatchee River? Staff evaluated the Northern Palm Beach County groundwater model as a possible tool to quantify impacts of water use on flow rates in the River. Results of this analysis are presented in **Appendix I**. Several factors limit the ability of this model to accurately estimate surface water flows in the River:

- Although the groundwater model provides summaries of inflows along specific reaches, it is not capable of directly calculating surface water flow rates in canals or rivers. An effort is underway to integrate the groundwater model with a surface water model and to calibrate these models with historical data. Additional work is needed to refine the models and improve the calibration.
- The degree of hydraulic connection between the aquifer and the canal or River have not been measured directly with sufficient precision (i.e. flow rates as low as 1 cfs). The rate of leakage out of or into a canal or river is highly influenced by this factor.

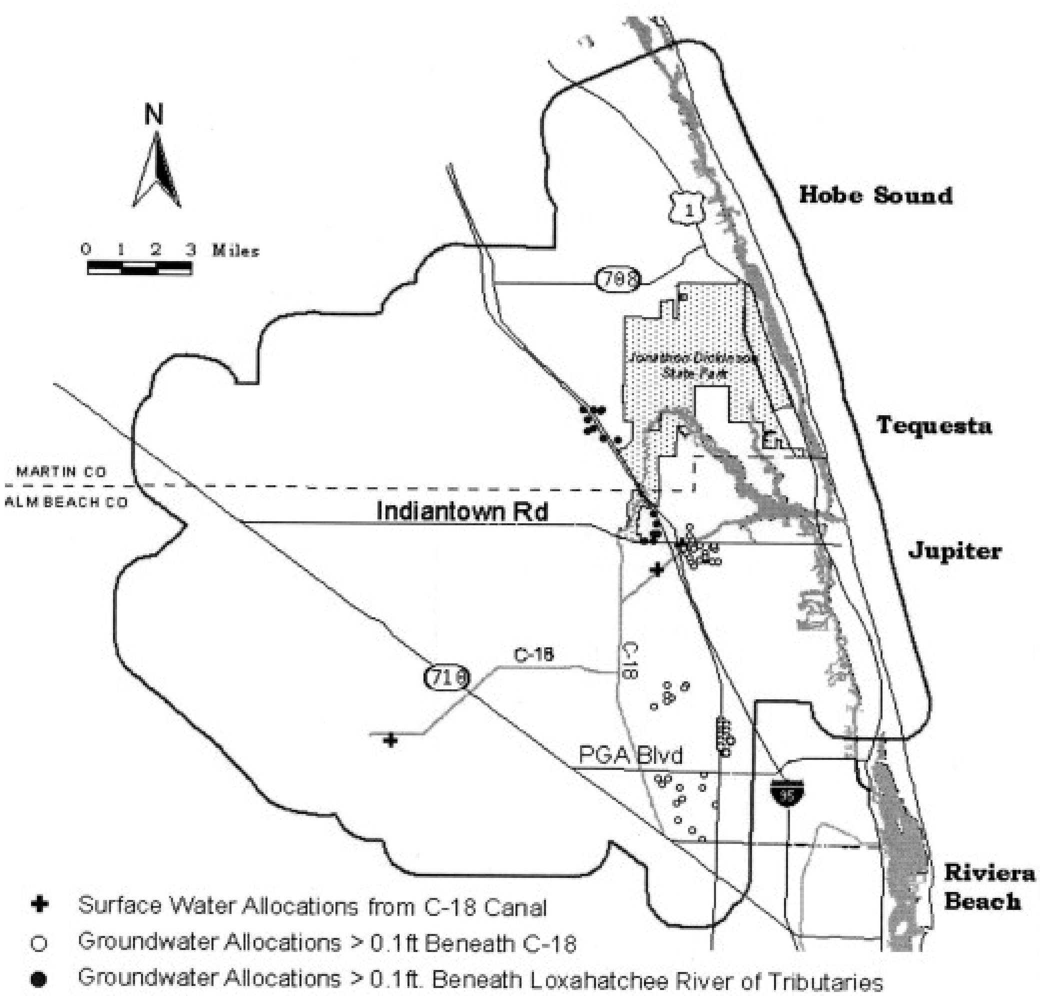


Figure 22. Location of permitted projects with potential to impact flows in the C-18 Canal, Loxahatchee River or tributaries (each permit consists of a cluster of dots that represent individual wells).

- The Northern Palm Beach model only includes the southern portion of the Loxahatchee watershed and hence does not include consumptive use withdrawals in Martin County.
- More data on the timing and amounts of actual water use in the watershed are needed to accurately quantify impacts of withdrawals.

As a result of these limitations, the model has limited capability to predict changes in Loxahatchee River flows associated with consumptive use. However, a qualitative assessment of water uses in the watershed yields the following:

- The three withdrawals from the C-18 Canal include a small nursery, an agriculture property located near the Corbett Wildlife Area and the Jupiter Siphon System. The nursery is only 25 acres and has an average daily allocation of 0.01 mgd. The agricultural project is located approximately nine miles upstream from the G-92 structure and was modified to include water supply from an onsite mine. The Jupiter Siphon System is used occasionally during extreme conditions, to withdraw water from the river and provide direct recharge to the Jupiter wellfield. Such withdrawals are limited and are only allowed to occur during times when the stage in the C-18 Canal is greater than 14.5 ft NGVD during the dry season. As a result, the system has only operated for 3 months during the last five years.

- There is one agricultural project whose allocation can produce a groundwater drawdown greater than 0.1 feet beneath the Loxahatchee River and one agricultural project that has the potential for drawdowns greater than 0.1 feet beneath tributaries to the river.
  - The first project, located in Palm Beach County, has not been used for several years and has been recently acquired by another owner. This project used groundwater that was pumped from wells located adjacent to the Turnpike and moved west to the crops located next to the river. The irrigation method permitted involves a seepage/flood application that raises the groundwater table to about 18 inches below the top of the bed. This raised the water table elevation located next to the River and actually increased ground water base flow to the River when the crops were being irrigated. Changes in the type of use (such as agricultural irrigation to golf course irrigation) would require a modification of the permit.
  - The second agricultural project is located in Martin County. The allocation for this project could produce between 0.2 to 0.3 ft of drawdown beneath portions of Kitchen Creek and Cypress Creek.
- The remaining four projects that cause drawdowns under the C-18 Canal include two golf courses, the Seacoast Utilities and Town of Jupiter Utilities. The range of drawdown for each of these projects beneath portions of C-18 Canal is between 0.2 and 0.3 ft.

The cumulative effect of these withdrawals is analyzed in **Appendix I**. Further information on individual permits is provided in **Appendix O**. While the ability of existing quantitative tools to calculate the impact of consumptive uses on the flow of the Loxahatchee River is limited, estimates based on simple flow net analysis and professional judgment indicate that the dry season impacts on flows that could potentially be delivered to the Northwest Fork are estimated to be less than 5 cfs. See **Appendix I** for further details.

BIOLOGICAL RESULTS

Importance of the Freshwater Floodplain Swamp

The freshwater floodplain swamp community located within the upstream portion of the Northwest Fork of the Loxahatchee River is an important component of the regional ecosystem. The structure of the floodplain swamp community is highly complex, comprised of low understory groundcovers and shrubs, medium height sub-canopy shrubs and hardwoods, and high canopy hardwoods, palms and bald cypress, including a number of cypress tress within the 300-500 year old range. The high canopy supports a wide variety of epiphytic plants such as ferns, bromeliads and orchids. The floodplain swamp community supports a number of important water resource functions for the ecosystem as follows: (1) provides leaf litter and organic detritus that are the basis of the food chain for upstream river system as well as the downstream estuary; (2) helps to stabilize the river shoreline and soils to prevent erosion; (3) provides specialized habitat for many plant and animal species, a number of which are rare, threatened or endangered; (4) maintains and protects water quality in the River; and (5) supports a diverse population of animals, including many that also utilize the surrounding upland and estuarine habitats. Wetland forest communities similar to those found along the upper reaches of the Loxahatchee River support both high wildlife density and diversity (Ewel 1990b).

In downstream reaches of the river, diversity of floodplain vegetation is reduced sharply by the influence of salt water. Mangroves are specifically adapted to live in saline environments, and because of their size, they tend to shade out other competing salt-tolerant wetland species such as cordgrass (*Spartina* spp.). Over time mangrove communities become essentially monocultures and hence have very low vascular plant species diversity. This low vascular plant species diversity, however, is compensated by the fact that mangroves produce large amounts of leaf litter that is used extensively by aquatic organisms as a food source and that many brackish water and marine species of algae and animals thrive in the extensive network of mangrove prop roots.

The long-term decline in the distribution and health of the floodplain swamp community within the mid to upstream portion of the Northwest Fork have been linked to periods of saltwater intrusion during low rainfall periods (Rodis 1973, Alexander and Crook 1975, Russell and McPherson 1984). These periodic episodes of increased salinity appear to be correlated with past hydrologic alterations of the river and its upstream watershed, as well as (potentially) long-term changes in rainfall patterns, climate, and sea level rise. These alterations most notably include the following: (a) the permanent opening of the Jupiter inlet in 1947, (b) dredging activities conducted within the estuary to improve navigation, and (c) construction of the C-18 Canal in 1957-58 which diverted freshwater flows away from the Northwest Fork to the Southwest Fork. Combined, all of these factors have resulted in reducing the amount freshwater flow delivered to River during dry periods and have increased the frequency that the floodplain swamp has been exposed to increased saltwater concentrations. Sufficient fresh water needs to be delivered to the river during dry periods to protect the remaining floodplain swamp community, a Valued Ecosystem Component, from further degradation and loss of natural function.

Because of its ecological importance to the region and surrounding communities, the focus of this report was on establishment of MFL technical criteria for the Northwest Fork to protect the remaining floodplain swamp community against significant harm. Due the lack of recent flow or biological data from the North Fork, and the highly altered nature of the Southwest Fork, these two arms of the Loxahatchee Estuary were not considered for MFL establishment at this time, but may be considered in the future as part of FDEP's MFL Priority List update.

The Effects of Salinity on Cypress Trees

An issue of primary concern during the preparation and review of the previous version of this report (SFWMD 2001) was the effect of salinity on bald cypress trees (*Taxodium distichum*). Because a close relationship between salinity levels and mortality of bald cypress could not be established, SFWMD scientists applied the methods that are used in the present study, which involve an assemblage of freshwater swamp species. However, since cypress trees are a dominant component in the "Wild" portion of the Northwest Fork, effects of salt water on this species are still a primary concern. In addition, the results of this investigation reveal trends and relationships that apply to other predominantly freshwater species. A more detailed treatment of this subject is provided in **Appendix A**.

Concepts to be Considered

Recent changes in the historic distribution of cypress trees along the Northwest Fork of the Loxahatchee River have been well documented (Alexander and Crook, 1975; Rodis 1973; SFWMD, 2002). The mechanisms related to these changes are not entirely understood, but there is a strong relationship between cypress tree die off and increasing levels of salinity within the river (Alexander and Crook, 1975; Rodis 1973). To understand the effects of elevated salinity on cypress trees, two salinity thresholds need to be considered: acute and chronic.

The acute threshold is the salinity level where trees are injured or killed after one exposure event. This may occur during a severe drought or from a surge of sea water pushed upstream during a storm event. Under such conditions, areas that are primarily freshwater systems become inundated with saltwater. As the magnitude of salinity and duration of exposure increase, the potential for injury or death to cypress increases. Effects are often visible within a short time from exposure (i.e. weeks to months).

The chronic threshold is the salinity level where bald cypress are injured or killed after long-term exposure. Unlike the transient drought or storm surge event described above, this threshold is characterized by continuous (or nearly so) exposure to low-level saline conditions. This exposure has the effect of crippling vital biological functions of the tree which can lead to developmental deformities, slowed growth rates, reduced canopy or leaf area, increased parasitism, and perhaps eventual death. Cypress suffering from salt stress are less disease resistant, less competitive ecologically, and less capable of producing viable offspring that are capable of regenerating the forest. Effects are usually only visible after a long period of exposure (i.e. months to years). The chronic threshold level is expected to be lower than the acute threshold level. Furthermore, differences between mature tree and seedling thresholds may be significant.

Of primary consideration in protection of the riverine swamp community is the provision of sufficient freshwater flow to prevent salt water from penetrating upstream. As more water flows through the river, the saltwater interface is pushed further downstream towards the ocean. Another important consideration is the effect of groundwater discharges and seeps to the river floodplain. Groundwater levels in areas adjacent to the river also influence the inland extent of saltwater intrusion. Typically, the depth at which saltwater intrusion occurs is directly related to the elevation of groundwater as shown in **Figure 23.**

Plant physiology, especially relative to root development, is another important factor that determines the response of a species to salinity flux. The depth and extent of root systems, and proximity to the edge of the floodplain both influence the potential for impact from elevated saline conditions.

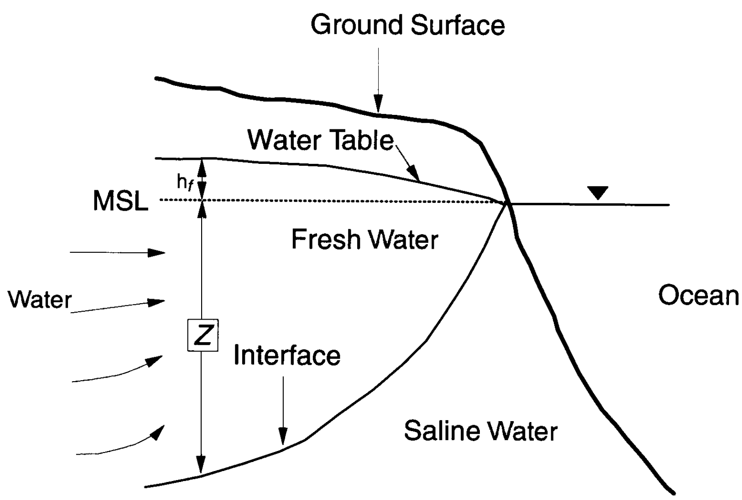


Figure 23. Relationship between water table elevation (h_f) and the depth below ground at which saltwater intrusion occurs (Z). As ground water level increases, the depth at which intrusion occurs also increases.

Tropical tree species (e.g. mangroves) typically develop shallow networks of roots near the soil surface. These species are more influenced by surface water conditions and variations. Temperate and subtropical tree species, including bald cypress, tend to be more deeply rooted and are more influenced by subsurface water quality. Established, mature trees near the edge of the floodplain are less affected by river salinity variations, since groundwater seepage from the uplands can maintain a head of freshwater against the salt water influx. Young saplings near the river channel are more likely to be damaged by periods of increased salinity. Other factors affecting the depth of root penetration include the presence of a hardpan or rock layer and the existence of anoxic conditions.

Literature Review

Rodis (1973) published his observations of the effects of elevated salinity on the cypress forests of the Loxahatchee River. He concluded that the primary cause of environmental problems facing the river was the upstream movement of saltwater, which, in turn, resulted in changes to the flora and fauna in JDSP, and other portions of the river. Results of this study indicated that a minimum continuous flow of 23,000 gallons per minute (50 cfs) was required across the Lainhart Dam to retard further upstream movement of saltwater in the Northwest Fork.

There currently are no salinity threshold studies of cypress trees in the Loxahatchee River Basin. Pezeshki et al. (1987), Allen et al. (1994) and Krauss et al. (1999) performed experiments on bald cypress seedlings from Louisiana and found that acute salinity toxicity effects occur above 2 ppt salinity. None of these experiments adequately covered the salinity range between 0 and 2 ppt. Therefore, a target cannot be determined from these studies for the acute salinity threshold for mature trees or for the chronic threshold for either seedlings or mature trees.

There are apparently no data to determine the relationships among groundwater levels, extent of saltwater penetration from the river to the edge of the floodplain, and depth below ground where saltwater occurs. Several studies have been initiated to determine the salt content and salt gradients in floodplain soils and shallow ground water, but results of these investigations have not been published (Roberts, personal communication; Worth, personal communication). Similarly, there are no data from the Loxahatchee River cypress community concerning the depth of the root zone or the relationship between cypress tree size and depth of root penetration.

Conclusions and Recommendations

- There have been no studies conducted to investigate the relationship between the extent of saltwater migration up the Loxahatchee River and the dieback of bald cypress trees in the floodplain.
- However indirect evidence and observations by a number of authors, indicates that there is a strong correlation between upstream saltwater encroachment and extensive dieoff of bald cypress, replacement of freshwater swamp by mangroves and other salt-tolerant species, and the current distribution of a “stressed” freshwater floodplain vegetation community in which cypress trees appear to be stunted and chlorotic.
- Maintenance of a viable cypress community in the Loxahatchee River floodplain needs to be based on consideration of both acute and chronic effects of salinity exposure.
- Results of studies conducted on Louisiana bald cypress seedlings suggest that exposure at or above 2 ppt salinity concentration may lead to symptoms of acute exposure, such as seedling injury or death. However, there are no indications from the literature on salinity levels that lead to stress or mortality of seedlings in the long term, or for mature trees.
- Additional research is needed to determine effects of salinity on bald cypress trees of different sizes, effects of groundwater interactions, salt content of floodplain soils at different depths and distances from the river, and the depth of cypress root penetration.

River Vegetation Survey Results

In order to develop a database that could be used to analyze river vegetation/salinity trends, a survey was conducted of existing vegetation communities along the river.

Semi-quantitative Survey

A semi-quantitative survey was conducted in November of 2000 and December of 2001 to examine community-based vegetation changes along the Northwest Fork of the Loxahatchee River. A total of 23 sites were surveyed as shown in **Figure 16, Chapter 4.** Measured vegetation parameters included species composition, and abundance. These data were then correlated with distance (in terms of river miles) upstream from the Jupiter Inlet, the primary source of salinity to the river. An additional 10 sites were surveyed in Kitching Creek.

Results from the November 2000 survey identified at least 35 species of vascular plants from 16 floodplain sites in the Northwest Fork (**Table 27**). These data indicate that the total number of plant (vascular macrophytes) species decreases dramatically from upstream freshwater habitats to downstream saltwater-dominated areas **(Figure 24).** These data indicate that a) observed vegetation trends were consistent in both the 2000 and 2001 surveys; b) the number of species increased as a function of distance from the inlet; c) the trend was consistent in both the Northwest Fork and Kitching Creek, and d) the number of species was correlated with salinity.

Table 27. Plant species observed in the Freshwater Segment of the Northwest Fork floodplain during quantitative and semiquantitative sampling periods, November, 2000 and January 2001

Scientific Name	Common Name	Scientific Name	Common Name
Acer rubrum	Red maple	*Osmunda regalis*	Royal fern
Annona glabra	Pond apple	*Persea borbonia*	Red bay
Aster caroliniana	Carolina aster	*Phlebodium aureum*	Golden polypody
Baccaris sp.	Saltbush	*Pleopeltis polypodioides*	Resurrection fern
Blechnum serrulatum	Swamp fern	Polygonum sp.	Swamp smartweed
Boehmeria cylindrica	False nettle	*Pontederia cordata*	Pickerelweed
Carya aquatica	Water hickory	*Quercus laurifolia*	Laurel oak
Crinum americanum	String lily	*Sabal palmetto*	Cabbage palm
Ficus aurea	Golden fig	*Salix caroliniana*	Swamp willow
Fraxinus caroliniana	Pop ash	Smilax sp.	Greenbriar
Hydrocotyl sp.	Water pennywort	*Taxodium distichum*	Baldcypress
Hyptis sp.		*Tillandsia balbisiana*	Air plant
Ilex cassine	Dahoon	*Tillandsia fasciculata*	Stiff-leafed wild pine
Ipomoea alba	Moon flower	*Tillandsia recurvata*	Ball moss
Itea virginica	Virginia willow	*Tillandsia setaceae*	Air plant
Ludwigia repens	Creeping primrose willow	*Tillandsia usneoides*	Spanish moss
Mikania scandens	Climbing hempvine	*Toxicodendron radicans*	Poison ivy
Nephrolepis sp.	Wild Boston fern	*Vitits munsoniana*	Wild grape

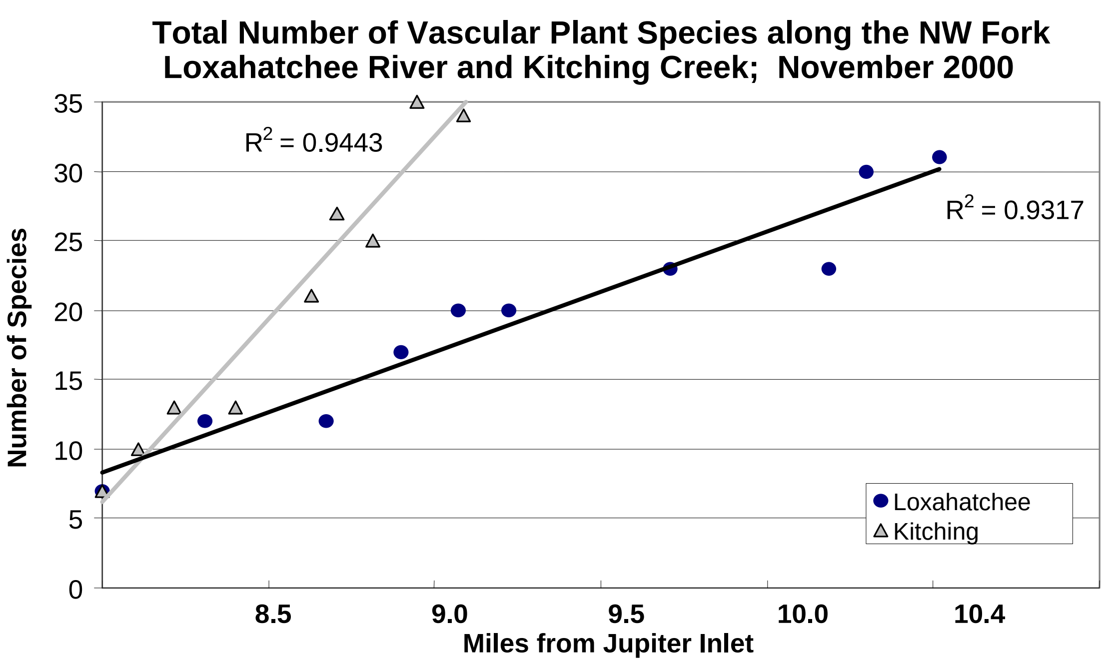


Figure 24. Number of Observed Vascular Plant Species versus river mile, Northwest Fork of the Loxahatchee River and Kitching Creek (November 2000).

Results of the semi-quantitative survey also showed that bald cypress and cabbage palm, as single species, appear to tolerate a wider range of salinity conditions within the river corridor than a number of other common floodplain swamp species. **Table 28** shows the distribution and abundance of common tree species that characterize the river's floodplain swamp forest. This relationship can be described by a linear equation ($R^2 = 0.93$) with upper and lower limits near 35 and 5 species (**Figure 24**). A similar trend was observed along Kitching Creek for data collected during the same period. These results suggest that the distribution of freshwater vegetation along the river is strongly correlated with the existing salinity gradient.

Table 28. Abundance Index*: Results of a semiquantitative vegetation survey at river vegetation sampling locations, Northwest Fork, Loxahatchee River (November 2000/December 2001).

Station Name	7A	7B	7C	V7	8A	8B	V6	8C	V5	8D	9A	9B	V4	9C	V3	10A	10B	V2	10C	V1
River mile	7.3	7.5	7.8	7.95	8.1	8.4	8.55	8.7	8.8	8.9	9.1	9.2	9.3	9.7	9.9	10.1	10.2	10.3	10.4	10.6
bald cypress	0	0	1	1	1	2	1	2	2	3.5	3	3	2	4	4	4	4	4	4	4
cabbage palm	2.5	3	3.5	2	4	3	2	3.5	3.5	3.5	4	3	3	3	3	3	3	2.5	2	3
red mangrove	4	4	4	4	4	4	4	4	4	4	4	4	3	2.5	2	0	0	1	0	0
pond apple	0	0	0	1	0	0	0	3	2	3	3	3	1	3	3.5	3.5	3	3	3.5	3.5
dahoon holly	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2	2	3.5	3	2
pop ash	0	0	0	0	0	0	0	0	0	0	0	1	0	2	2	2	2	2	2	2.5
red maple	0	0	0	0	0	0	0	0	0	1	1	1	0	2	1	3	3	3	3.5	3.5
Virginia willow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2.5	2	3.5
red bay	0	0	0	0	0	0	0	0	0	0	0	0	1.5	0	0	0	1.5	1	0	1.5

* Abundance Index
4 = Highly abundant or dense population (>75% cover), a dominant component of the plant community
3 = Common; widespread and of moderate density but not a dominant component of the plant community
2 = Sparse; widespread and of low density or restricted to localized populations
1 = Two or less individuals; rare
0 = Species not present

A second semi-quantitative survey was repeated in December 2001 at seven additional sites. These results showed a similar trend as reported for the previous survey, with a R^2 of 0.97 reported (**Figure 25**), but exhibited higher total number of species.

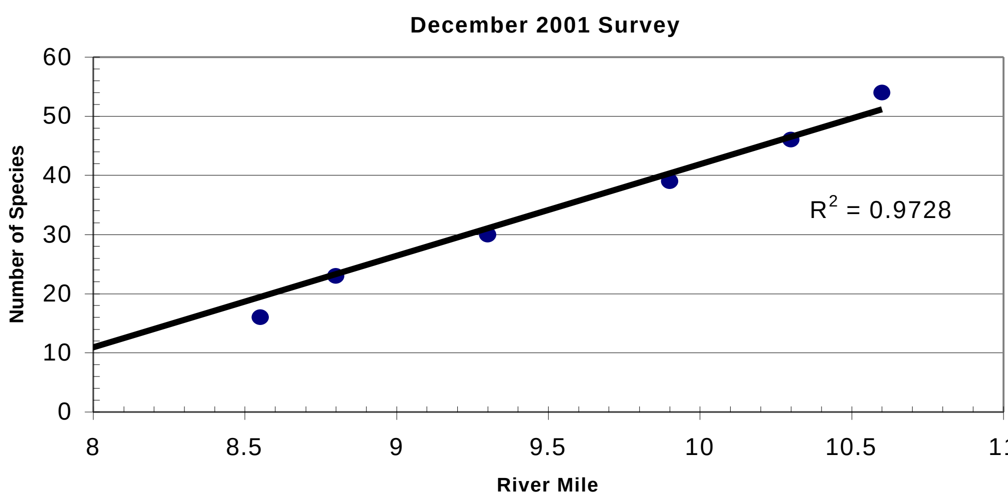


Figure 25. Relationship between total number of vascular plant species and location (river mile) along the Northwest Fork of the Loxahatchee River (December 2001 survey).

Differences in the total number of species observed could be accounted for by differences in rainfall patterns and the number of herbaceous species recorded between the two surveys. Although more species were reported than during the 2000 survey, as perhaps would be expected after a major drought period, the significant positive trend shows that total number of floodplain vascular plant species increases with distance from the inlet and decreases at those stations (with observed higher salinity values) located nearer to the inlet. This relationship provides further evidence that salinity plays an important role in regulating plant community species composition and distribution along the Northwest Fork of the Loxahatchee River. As shown in **Table 28,** the distribution and abundance of red maple, dahoon holly, pop ash, pond apple, red bay, and Virginia willow all appear to be impacted within a very short segment of the river as compared to bald cypress or cabbage palm. As a group, these six freshwater species were limited in their distribution along the river suggesting that they may be more sensitive to long-term changes in salinity as compared to bald cypress, cabbage palm or red mangrove communities.

Table 29 provides a list of these six key species and their generalized salinity tolerances obtained from a review of the literature. The river survey data also indicates that bald cypress, used as a single indicator species, is not the most sensitive indicator of salinity stress within the Northwest Fork of the Loxahatchee River. Based on these relationships, District staff chose the following six species (red maple, pop ash, red bay, Virginia willow, dahoon holly, and pond apple) as indicator species for the selected "valued ecosystem component" (VEC) for the Northwest Fork (see later section of this report entitled, *Proposed VEC for the Northwest Fork of the Loxahatchee River*). In order for a species to maintain itself at a particular location, not only must the plants (trees) survive, but they must also be able to replace themselves over time by successful reproduction. These plants must thus be able to produce viable seeds, the seeds must germinate, and seedlings and saplings must survive to an adult seed-producing stage. These various life stages may have different salinity tolerances.

Table 29. Key species identified along the Northwest Fork and their salinity tolerances.

Species	Saltwater Tolerance
Selected "KEY" Species	
Red maple *(Acer rubrum)*	Freshwater[a]
Pop ash (*Fraxinus caroliniana*)	Freshwater[a]
Virginia willow (*Itea virginica*)	Freshwater[a]
Dahoon holly (*Ilex cassine*)	Freshwater[a]
Red Bay (*Persea borbonia*)	Freshwater[a]
Pond apple (*Annona glabra*)	Freshwater[a]
Other Dominant River Vegetation Species	
Bald cypress (*Taxodium distichum*)	Freshwater to slight salt tolerance[c]
Cabbage palm (*Sabal palmetto*)	Freshwater to slight salt tolerance[b]
Red mangrove (*Rhizophora mangle*)	Salt tolerant[a]

[a] see Tobe, et al. 1998. Tobe, et al. 1998 is a primarily a plant identification manual and gives generalized habitat descriptions rather than specific salinity tolerance of the species listed in the table
[b] Cabbage palm is generally associated with freshwater and coastal swamps
[c] see Allen 1994; Allen et al. 1994, 1997; Conner 1992; Javanshir & Ewel 1993, Pezeshki et al. 1986, 1987, 1990, 1995.

Quantitative Survey

In January 2002, a quantitative vegetation survey was conducted along the Northwest Fork. In this survey District staff selected 9 of the original 23 vegetation sampling sites recording both plant community-based and species-based information. **Figure 16 (Chapter 4)** shows the location of the nine quantitative vegetation-sampling sites that were resurveyed in January 2002.

Eight of these sites (sites V7, 8B, 8D, 9A, 9B, 9C, 10B and V1) were used to compare findings against previously collected semi-quantitative data. Three sites (V1, V3, and V7) were used as model verification sites (**Figure 16, Chapter 4**). The following community-based and species based parameters were measured at each site:

- Presence or absence of selected VEC species
- Number of individuals of VEC species
- Age class of VEC species (mature tree, sapling, seedling, and stump spouts)
- Tree height of VEC species
- Trunk circumference at breast height of VEC species
- Canopy diameter of VEC species

Details regarding sampling methods for the vegetation surveys and field data from vegetation surveys are presented in **Appendix C** of this report.

Number of Adults

Table 30 provides a summary of the total number of adult and saplings tree VEC indicator species recorded at each quantitative vegetation survey site.

Table 30. Number of adults and saplings of selected tree species recorded during the January 2002 quantitative vegetation survey, at eight locations along Northwest Fork.

	Station Name	**V1**	**10B**	**9C**	**9B**	**9A**	**8C**	**8B**	**V7**
	River mile	**10.6**	**10.2**	**9.7**	**9.2**	**9.1**	**8.7**	**8.4**	**7.95**
VEC Indicator Species	**popash**	39	40	35	2	1	0	0	0
	red bay	4	7	6	0	0	0	0	0
	dahoon holly	1	20	5	2	0	0	0	0
	Virginia willow	123	47	35	0	1	0	0	0
	red maple	22	16	10	0	0	0	0	0
	pond apple	17	52	42	13	24	0	0	0
Other Species	**bald cypress**	22	58	33	4	4	4	3	0
	cabbage palm	19	31	43	33	13	11	47	46
	red mangrove	0	1	18	200*	200*	180	200*	200*

* Due to the large number of red mangrove trees present at sites V7 – 9B, values were estimated

Results show that downstream of river mile 9.1 most of the six VEC indicator species were not present in the floodplain swamp. At river mile 9.2 only three VEC indicator species are present; while upstream all six VEC indicator species are present.

Tree Height and Trunk Diameter

Measurement of physical features such as trunk diameter (DBH) and tree height showed a similar trend to that indicated by the numbers of adults and saplings. As one moves downstream from river miles 10.6 to 9.1 there is a trend of both reduced tree height and trunk diameter suggesting these communities have been physiologically stressed due to periodic exposure to increased salinity levels in areas nearer to the Jupiter inlet (**Table 31**).

Table 31. Mean trunk diameter (DBH) and mean tree height of adults at eight river vegetation sampling locations, Northwest Fork of the Loxahatchee River (January 2002)

Station Name	**V1**	**10B**	**9C**	**9B**	**9A**	**8C**	**8B**	**V7**
River mile	**10.6**	**10.2**	**9.7**	**9.2**	**9.1**	**8.7**	**8.4**	**7.95**
Mean Trunk Diameter/Tree Height (in feet)								
VEC Indicator Species								
pond apple	1.8/24	1.0/20	0.4/15	0.3/14	0.5/9	0/0	0/0	0/0
dahoon holly	0.6/28	0.3/17	0.1/12	0.2/13	0/0	0/0	0/0	0/0
pop ash	0.9/19	0.5/19	0.2/13	0.3/14	0.3/11	0/0	0/0	0/0
red maple	1.4/29	0.7/22	0.4/24	0/0	0/0	0/0	0/0	0/0
red bay	0.1/18	0.2/20	0.1/8	0/0	0/0	0/0	0/0	0/0
Other Species								
bald cypress	3.2/43	0.7/23	0.9/32	NA/27	0.3/14	1.0/17	NA/25	0/0
cabbage palm	NA/25	NA/30	NA/24	NA/19	NA/14	NA/11	NA/19	NA/15
red mangrove	0/0	NA/12	NA/9	NA/14	NA/9	NA/9	NA/8	NA/8

NA = data not available; Calculations based on measurement of adult species;
Note: Virginia willow is a shrub and therefore was not measured using the above methods.

Number of Saplings and Seedlings Present

Observations of the number of saplings or seedlings present at each site were important for determining if the community is reproducing and sustainable (**Table 32**). Adults were identified as individuals at canopy height while saplings were less than canopy height, but greater than breast height, and seedlings were those individuals less than breast height. The presence or absence of saplings or seedlings was also considered a more sensitive indicator of the degree that saltwater may impact the community over time. That is, under low salinities it may be possible to sustain adult trees, however seedlings or very young tress may not be able to survive.

Results of the vegetation survey show that very few saplings or seedlings of VEC indicator species are present downstream of river mile 9.2, suggesting that this community can no longer reproduce, is not sustainable, and thus has experienced significant harm (**Table 32**). At river mile 9.7, the number of VEC indicator species saplings and seedlings appear to be reduced in comparison to upstream areas, indicating that this section of the river is currently stressed by periodic exposure to low salinity levels.

Canopy Cover

A primary aspect of forest structure that plays an important role in the ecology of the floodplain swamp is the canopy. Bald cypress' tendency to dominate wetland forests is largely due to their ability to form a high closed canopy, which is particularly evident during the growing season. Within the Wild and Scenic portion of the Loxahatchee River the floodplain swamp

Table 32. Number of saplings and seedlings present at eight river vegetation sampling locations, Northwest Fork of the Loxahatchee River (January 2002).

Station name	**V1**	**10B**	**9C**	**9B**	**9A**	**8C**	**8B**	**V7**
River mile	**10.6**	**10.2**	**9.7**	**9.2**	**9.1**	**8.7**	**8.4**	**7.95**
Number of Seedlings/Saplings Present								
VEC Indicator Species								
pond apple	0/1	0/10	1/3	0/0	1/0	0/0	0/0	0/0
dahoon holly	0/0	7/0	1/0	0/0	0/0	0/0	0/0	0/0
pop ash	6/13	5/3	3/0	0/0	1/0	0/0	0/0	0/0
red maple	1/44	5/38	0/0	0/0	0/0	0/0	0/0	0/0
virginia willow	63/NA	20/NA	9/NA	0/NA	1/NA	0/NA	0/NA	0/NA
Red bay	1/1	3/11	4/0	0/0	0/0	0/0	0/0	0/0
Other Species								
bald cypress	1/0	24/7	5/0	0/0	4/0	0/0	0/0	0/0
cabbage palm	0/0	1/0	0/0	0/0	0/0	0/0	0/0	0/0
red mangrove	0/0	0/0	2/27	NA	NA	NA	NA	NA

NA = data not available, transect inaccessible.

canopy supports a large array of air plants, bromeliads, and orchids, many of which are federally threatened or endangered species (FDEP and SFWMD 2000). The canopy plays a critical role in the life cycles of many birds, reptiles, and insects. The canopy also regulates the microclimate of the forest, controlling humidity, light quality, rainfall distribution and other physical parameters that can have profound influences on plant growth.

In this study, tree canopy areas within various tree height classes were calculated from tree canopy diameter measurements (see **Appendix C** for methods). **Figure 26** shows striking changes in canopy cover area for the six selected VEC indicator species associated with distance (river mile) upstream from the Jupiter Inlet. Major changes in canopy cover were measured between river miles 9.7 and 9.2 indicating a change in the floodplain swamp forest structure between these two sites. Upstream (at river miles 10.2 and 10.6), the floodplain forest appears as a complex structure with a high canopy dominated by bald cypress (between 35–60 ft. in height) and a secondary canopy dominated by mixed hardwoods, bald cypress, and pond apple (between 15-30 ft. in height) (**Figure 26)**. Some shrubby species are found below the secondary canopy, at less than 10 ft in height. A short distance downstream at river mile 9.7, the structure of floodplain forest shows a decrease in the area of the high canopy strata. At river mile 9.2 the high canopy has been virtually eliminated and has been replaced by a low canopy dominated by red mangroves approximately 15 ft above the ground surface. These changes in forest structure can have profound effects on microclimate, ecological function, and species composition (both flora and fauna) of the floodplain swamp forest.

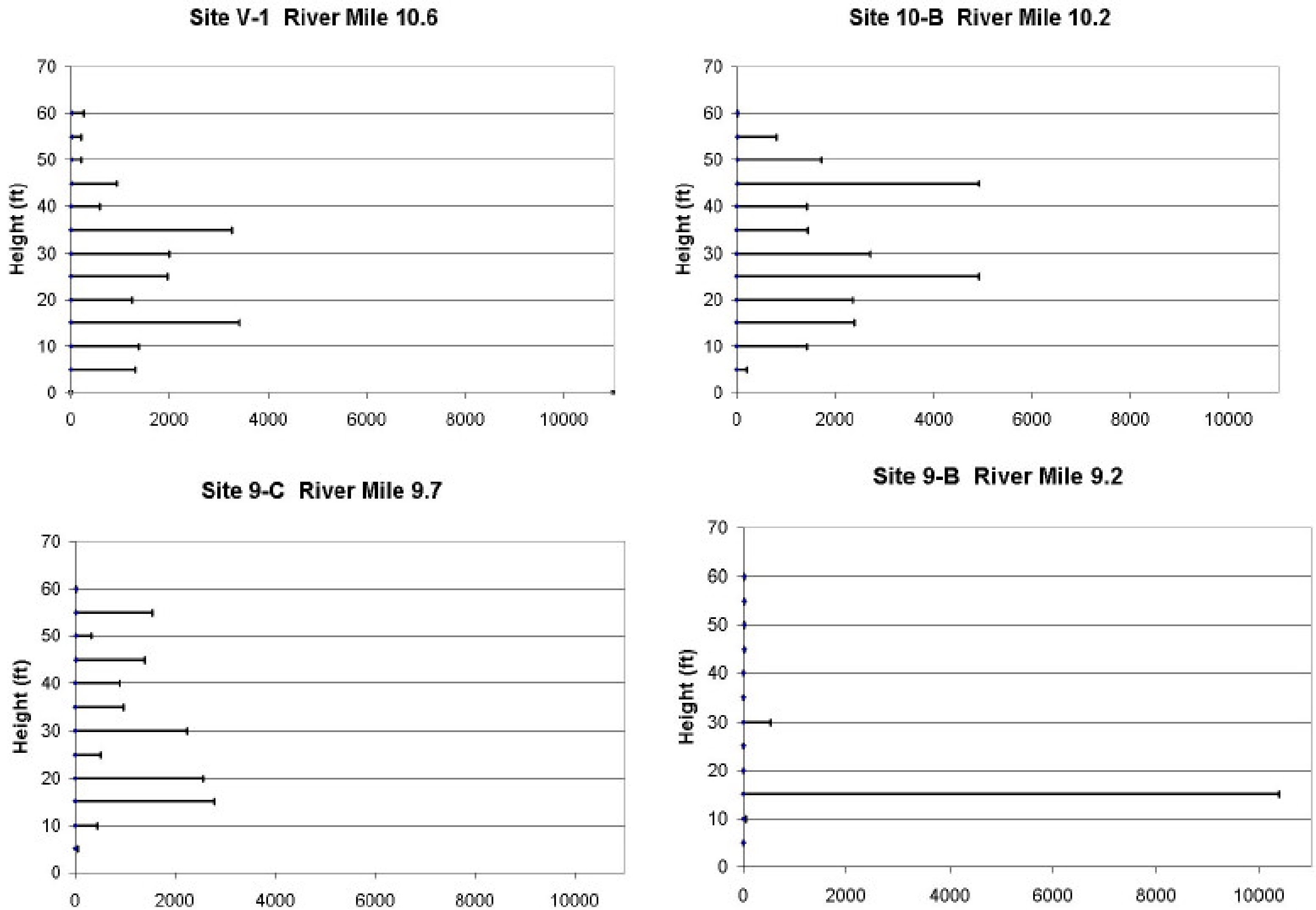


Figure 26. Total Forest Canopy Area Within Height Classes for four sites along the Northwest Fork of the Loxahatchee River.

Vegetation Changes along the Northwest Fork Since 1985

A baseline or reference point must be identified as a basis to establish an MFL. The SFWMD staff selected the condition of the river at the time that Northwest Fork was designated as a "Wild and Scenic River," in 1985. This point was chosen because the river management Plan (SFWMD, 2002) recognized the values of the river at that time and identified the need to protect and enhance these resources. In addition, several types of information are available to provide a description of the condition of the resource at that time.

A review of reports and documentation of vegetation communities along the Northwest Fork was conducted in order to determine the extent of vegetation communities when the River was federally designated as "Wild & Scenic". This information is also useful to determine if the vegetation is still changing when compared with the current (2002) vegetation surveys (see **Figure B-9, Figure B-10** in **Appendix B** and **Table 1** in **Chapter 2**). Reports that were reviewed include the Final Wild and Scenic River Study Environmental Impact Statement (EIS)(United States Department of the Interior/National Park Service, 1984) and the Loxahatchee River National Wild and Scenic River Management Plan (FDEP & SFWMD, 2000).

The EIS provides a map of river vegetation (**Figure 27-A**) and generally describes the vegetation of the river from its source upstream of Indiantown Rd. to the mouth of the Jupiter Inlet. Vegetation was described as a canopied cypress river-swamp community from Indiantown Rd. to the Trapper Nelson Interpretive Site. Downstream of Trapper Nelson's the vegetation changed and was described as mangrove-dominated swamp with dead cypress trees at river mile 9.2. At river mile 10.1, the first mangroves are found and most cypress trees appeared to be stressed. Current vegetation studies indicate that the area of stressed freshwater swamp hardwoods and cypress begins further downstream, near river mile 9.7.

It is not known why there is a discrepancy between the location of the "stressed" area at river mile 10.1 during 1984 and at river mile 9.7 during 2002, however a couple of explanations are plausible. It may be possible that observations were made at different times of the year or different criteria were used to identify "stress." Other explanations may include differences in vegetation sampling methodology, that increased rainfall and flows to the Northwest Fork during the 1990's have led to some recovery of the swamp forest in the area around river mile 10.1 or that measurements of river mile locations differed significantly.

The River Management Plan (FDEP & SFWMD, 2000) also provides a description and map of vegetation along the NW Fork (**Figure 27-B**), based on a survey conducted by the Florida Park Service in 1993 (FDNR 1994). This document indicates that the cypress community "solidly flanks the river and its tributaries upstream from about river mile 9.5 [SFWMD river mile 10.1], and is the dominant species to above river mile 9 [SFWMD river mile 9.2]. The mangrove community solidly lines the river downstream from river mile 9 [SFWMD river mile 9.2]. . . dead cypress trees tower above the red mangroves for one or two miles downstream from this point, evidence of the extent of freshwater vegetation that existed before changes in the upstream movement of salt water."

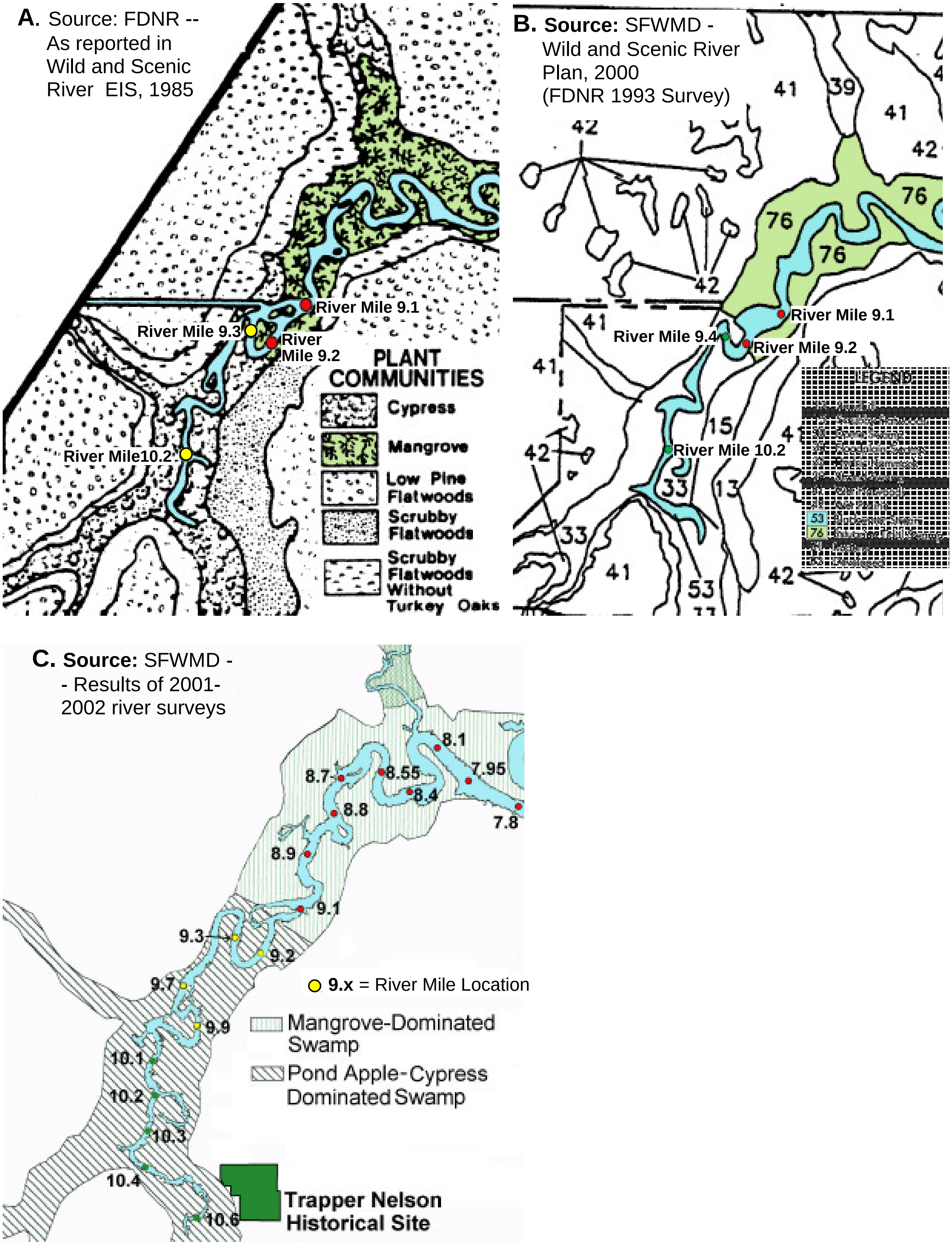


Figure 27. Maps showing results of vegetation surveys along the Northwest Fork, 1985-2000. River mile locations determined by SFWMD during 2000 surveys.

This observation is in line with vegetation data collected along the Northwest Fork in studies from 2000-2002 (**Table 32** and **Figure 27-C**), which indicates that the vegetation zones classified by SFWMD as “pond apple-cypress dominated”, and “mangrove-dominated” closely correspond to the same locations that were identified as “floodplain swamp” and “estuarine tidal swamp in the 1993 surveys and as “cypress” and “mangrove” in the 1985 survey, respectively. Based on this comparison of vegetation community descriptions from 1985 and 2002, it can be inferred that there has been little change in the distribution of freshwater and salt-tolerant vegetation in this section of the river since the mid-1980’s.

However, it is quite possible that there has been a visibly slight, but continuing, decline in the extent of the freshwater community, especially since there is no information on the *health* of the VEC species or the impacts to seedling germination and survival. The information presented primarily supports the conclusion that changes in the extent of cypress and other major tree species seems to have stabilized. As was noted earlier in the report, canopy species may take longer to respond to stress than the rest of the floodplain community, so that substantial changes may have occurred in the herbaceous species, seedlings and saplings during this period.

Other Factors Considered that May Affect Vegetation Distribution

The vegetation survey data collected along the Northwest Fork of the Loxahatchee River documents that a gradient of change occurs, from a freshwater-dominated floodplain swamp to a saltwater-tolerant red mangrove community. These observed changes appear to be highly correlated with distance from the Jupiter inlet and the salinity gradient that exists along the Northwest Fork. We also considered other factors that may explain the current distribution of river vegetation species found along the Northwest Fork. These include possible changes in fire frequency, excessive flooding, and the effects of drought. A review of the literature relative to bald cypress and aerial photography/GIS studies of long-term vegetation changes in the basin as presented in this report indicates that none of these factors can account for the overall pattern of vegetation change observed during the past half-century.

Fire frequency in the river floodplain is generally low, primarily because the soils are saturated most of the year, which retards the spread of fire. Furthermore, dry fuel in the floodplain swamp is sparse, and rapid decomposition rates and frequent flood events tend to clear away fuel. Bald cypress and mixed hardwood forests thrive in both fire free habitats and in occasionally burned areas (see Gunderson 1984, Ewel 1990a). Bald cypress have been found to recolonize after fire, if a local seed source is available (Gunderson 1984).

Excessive or prolonged flooding of the floodplain along the Northwest Fork is unlikely, especially since historic water tables have been reduced and hydroperiods shortened over the past century (see Aerial Photography/GIS studies, **Appendix B**). In spite of this, flooding may be more frequent along downstream segments where tidal action is a dominant hydrological force. However, bald cypress have been found to grow naturally in flooded swamps and lakes 90-100 m from the shoreline, some in water 1-3 m or more deep and at time of floods, the depth may be greater for short intervals (Brown 1984, Lugo and Brown 1984). Conversely, bald cypress are successfully grown in moist soils as well as in much drier landscape situations where flooding never or rarely occurs. Drought would induce short-term restrictions on growth of bald cypress, but would not explain the pattern of loss we have observed along the River. If either of these factors (prolonged flood or drought) had a major influence on the loss of bald cypress and mixed hardwoods along the Northwest Fork, it would be expected to cause widespread loss across the floodplain, rather than only along a front that is closely associated with distance from the inlet.

Effects of Freshwater Inflows on the Loxahatchee Estuary

Major Features of the Estuary

Physical and biological features of the estuary are summarized on pages 26-39. The North Fork portion of the estuary is very small in extent and has very limited resources due to several factors. The lower reaches have been extensively bulkheaded and filled, effectively eliminating important shoreline habitat. In addition, large areas of the bottom consist of soft mud or ooze that is not conducive to supporting estuarine benthic communities. The upper reaches within Jonathon Dickinson State Park in this section of the North Fork Loxahatchee River have steep shorelines that do not support significant amounts of marsh or swamp shoreline vegetation.

The Southwest Fork is very small in size and has limited resources, due to extensive bulkheading and development of the shoreline and the relatively frequent, large-volume discharges of freshwater from S-46 that result in scouring of the substrate and rapid and extreme changes of the salinity regime.

None of the resources or issues in the North Fork or Southwest Fork of the estuary were considered to have a significant function that would be impacted by low flow conditions. In contrast, the resources of the Northwest Fork, Central Embayment and adjacent coastal waters are considered to be sensitive to high flow events. When discharges on the order of 2,000 to 3,000 cfs occur through the S-46 structure into the Southwest Fork, the entire estuary can become freshwater, which has significant adverse effects on marine life, especially seagrasses and benthic macroinvertebrates. These types of high discharge events also result in displacement and loss of habitat for fishes that prefer more saline conditions.

By contrast, the Northwest Fork of the estuary comprises the largest area of brackish water environment. The mud and sand substrates support a variety of benthic communities that are adapted to a changing salinity environment, high turbidity and low light levels in the water column. Significant numbers of oysters live on the bottom and attached to mangroves beginning about river mile 4.0 and extending upstream to approximately river mile 7 (see **Figure 2**). Due to the connection between persistent freshwater and marine environments, the Northwest Fork has the highest quality estuarine conditions within the system and the resources that most need to be protected from significant harm.

Effects of High Rates of Freshwater Discharge

Resources in the Loxahatchee Estuary are more at risk due to the effects of high rates of freshwater discharge than the effects of low flow. During periods of high discharge, on the order of 1,200 cfs may be discharged from the Northwest Fork and 2,000 to 3,000 or more cfs may be discharged from the Southwest Fork. Under such conditions, the entire estuary and adjacent waters are converted to fresh water in a relatively short period of time (hours or days). This has significant adverse effects on marine life in these areas, especially benthic organisms such as seagrasses and oysters, due to rapid and extreme salinity change, siltation and high turbidity, but also results in displacement of freshwater species (fishes, amphibians and reptiles) downstream into areas that will subsequently revert back to marine conditions. The effects of such discharge events may persist for months or years before full recovery can occur.

Effects of Low Rates of Freshwater Discharge

During periods of low flow, saltwater intrudes upstream within the Northwest Fork, as noted throughout this document. Salinity conditions in the estuary were monitored in 1981 during a low flow period, when flow from the Northwest Fork equaled 9 cfs (Russell and McPherson 1984). Data collected during this period indicated that salinities from the inlet through the central embayment were above 35 ppt. Salinities at the surface of the Northwest Fork of the estuary and along the bottom of the upper end of the Northwest Fork, extending up to river mile 4.1, exhibited salinities in the range from 30-35 ppt (see data from Russell and McPherson 1984, presented in **Appendix F**, **page F-6**). Further upstream, in the Northwest Fork near Kitching Creek, salinities were recorded within the range of 20-25 ppt (see **Appendix F**, page **F-7**).

Importance of Maintaining Low-Salinity Conditions

An important aspect of protecting the estuarine character of this system is to maintain an oligohaline (low salinity less than 5ppt) zone. Such low-salinity environments provide important habitat for a wide variety of plants and animals that utilize this resource (SFWMD 2002, Estevez 1999). Assessment of fisheries resources in the estuary, indicate that many such organisms are present in the Loxahatchee River system, including mullet, seatrout, snook, tarpon, blue crabs and shrimp. In other systems (such as the St. Lucie and Caloosahatchee estuaries) it has been demonstrated that a complete loss of oligohaline habitats during the winter and spring months (dry season) has a significant adverse effect on many organisms that utilize this zone during their early life history stages. In some cases, these impacts may last for two years or more, (SFWMD 2001, SFWMD 2002).

PROPOSED VEC FOR THE NORTHWEST FORK

Rationale for VEC Selection

The SFWMD Loxahatchee River research program supports application of a resource-based management strategy defined as the "Valued Ecosystem Component" (VEC) approach. This evaluation methodology is similar to a program developed as part of the National Estuary Program (USEPA 1987). For the purposes of this study, the VEC approach is based on the concept that management goals for the Northwest Fork of the Loxahatchee River can best be achieved by providing suitable environmental conditions that will support certain key species, or key groups of species, that inhabit the system. In some instances the VEC represents those species that are most sensitive to the environmental factor of interest. Protection of these species assumes protection of the entire community. A VEC can be defined as a species, community or set of environmental conditions and associated biological communities that are considered to be critical for maintaining the ecological sustainability of the Northwest Fork's floodplain swamp community.

Based on the results of a vegetation survey of the Northwest Fork of the river (presented previously in this chapter), District staff propose that the freshwater floodplain swamp is the VEC for the Northwest Fork of the Loxahatchee River. In order to monitor the "health" of this VEC, a group of six key woody vegetation species that characterize the upstream floodplain swamp forest were selected to represent the VEC for the purpose of establishing a MFL for the Northwest Fork of the Loxahatchee River. Impacts to the VEC indicator species beyond a critical level are considered to constitute significant harm to the floodplain swamp community. The VEC approach was applied to the Northwest Fork of the Loxahatchee River based on the following relationships:

Results of two river vegetation surveys showed that the bald cypress community is not a sensitive indicator of salinity stress within the Northwest Fork of the Loxahatchee River.

- These results showed that six "key" woody vegetation species (red maple, pop ash, red bay, Virginia willow, Dahoon holly, and pond apple), which are characteristic of the floodplain swamp, appear to be more responsive to long-term changes in river salinity than cypress, cabbage palm or red mangrove communities, and therefore qualify as a more sensitive indicator of the VEC for the Northwest Fork of the Loxahatchee River.
- These six species have physiological characteristics that play important functional roles in the forest ecology. These species are also more sensitive to salinity stress than bald cypress and can be useful in inferring the overall health of the freshwater floodplain swamp. These characteristics also make them useful indicators of long-term salinity conditions.
- Based on these relationships, District staff selected the six species listed in **Table 29** as VEC indicator species for the Northwest Fork of the Loxahatchee River.

Species Selected as Representative of the Proposed VEC

"Key" species as defined in this study refer to those selected from the results of the river survey and a corresponding literature review (**Table 29**) of vegetation salinity tolerances. Key species were selected based on their ability to measure responses within the "two-year or more" timeframe that is the basis for significant harm. The criteria for selection of these key species were as follows:

- Species that play important roles in freshwater swamp ecology by providing food, substrate or habitat for other species and thus are useful indicators of long-term ecosystem health.
- Species that are widely distributed within the floodplain corridor and in South Florida freshwater swamps (i.e. not found only in localized populations). This criterion is used to ensure that observed trends are most likely not due to natural variability that could account

for uneven distributions.

- Species that are significant components of the local riverine swamp community in terms of density and physical forest structure. This criterion was intended to exclude minor (rare) species and to select those that were primary constituents of forest structure, and whose overall abundance can be reliably measured by reasonable sample sizes.
- Terrestrial species that are rooted in the soil substrate (i.e. not floating or epiphytic). This excludes aquatics, which may reflect only short-term (transient) salinity conditions.
- Species that are relatively long lived (more than 10 years, i.e. generally woody or tree species), which are more reliable indicators of long-term conditions. Herbaceous species were excluded, as they typically have shorter life spans (less than 10 years).
- Species that occupy different ecological niches and have different functional roles in the freshwater swamp (i.e. canopy, sub-canopy, shrubby). A decline in one or more of these functional roles can have ecological consequences, such as impacts to wildlife.
- Species that are copious producers of differing seed types (e.g. berries, samaras, etc.) that are readily spread (e.g. air-borne, water-borne, bird-dispersed) throughout the area. This helps to ensure that an observed decline in seedling or sapling numbers is not related to localized seed production or species-specific dispersal characteristics.
- Species that represent a range of saltwater tolerance and sensitivities (i.e. obligate freshwater species, saltwater tolerant species, and transitional species). This characteristic will help to document the range of salinities and changes along the Northwest Fork.

Information gathered from the vegetation survey indicated that a group of nine species would fit the criteria described above. These species are listed in **Table 29** along with their relative salinity tolerances obtained from a review of the available literature.

As the District and other agencies proceed with restoration efforts for the Loxahatchee River other key indicator species and criteria will need to be developed. Thus, the canopy species could be included as indicator of the very long-term conditions associated with recovery of damaged floodplain community structure and herbaceous species could be included as indicators of the effectiveness of short-term hydrologic changes. All strata should eventually be analyzed during vegetation surveys to give a more complete picture of health of the river's plant communities. More detailed studies will be needed that include a larger assortment of species. Additionally, as the District refines the restoration efforts and MFL analysis to include other segments of the ecosystem, indicators for invertebrate and vertebrate populations may also need to be identified

Summary

- Overall, the vegetation survey data collected along the Northwest Fork of the Loxahatchee River shows that a gradient of change exists, from a freshwater-dominated floodplain swamp to a saltwater-tolerant red mangrove swamp.
- Results of quantitative and semi-quantitative surveys showed declines in number of VEC

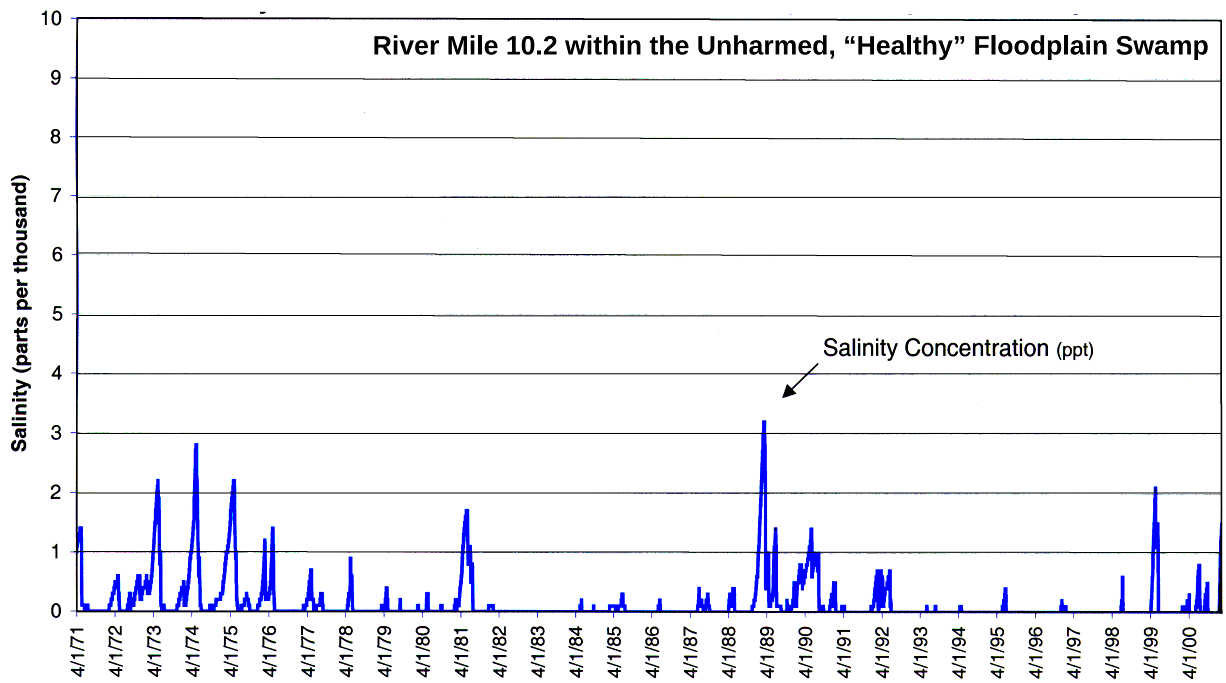
indicator species, number of individuals, canopy area, tree height, tree trunk diameter, and the number of seedlings and saplings present at river vegetation sampling sites located closer to the Jupiter inlet, which is the source of salinity for the Northwest Fork.

- Quantitative survey results also showed that locations at and above river mile 10.2 have a full canopy cover and contain reproducing populations of cypress and all six VEC indicator species that are characteristic of the floodplain swamp community. From these data, District staff concluded that this area of the river currently represents an unharmed, healthy, sustainable floodplain swamp community.
- Results of semi-quantitative survey indicate that a healthy floodplain swamp community probably continues to exist downstream to river mile 9.8
- At river mile 9.7, although all six VEC indicator species were present, there were observed reductions in canopy cover, a decline in the mean height and trunk diameter of VEC tree species, and a reduction in the number of seedlings and saplings present. These results suggest that several functional characteristics of the floodplain swamp at this location in the river have been, or currently are, stressed by periodic exposure to low salinity levels.
- The most significant result of this study shows that downstream of river mile 9.1 all six VEC indicator species were eliminated from the floodplain and replaced by saltwater-tolerant mangroves. A short distance upstream at river mile 9.2, no VEC saplings or seedlings were present and only three out of the six VEC species remained as part of the floodplain swamp forest. In addition, the high canopy has been virtually eliminated and replaced by a low canopy dominated by red mangroves at river mile 9.2.
- These observed changes in species composition, forest structure, and reproduction capabilities strongly indicate that a major change has occurred to the floodplain swamp forest community that can affect the microclimate, ecological function, and species composition of both flora and fauna within the Northwest Fork. For these reasons, river mile 9.2 was selected as the baseline location in the river where significant harm occurs.

APPLICATION OF MODELING TOOLS

Analysis of the Simulated Long-term Salinity Record

Since long-term salinity records do not exist for each vegetation sampling site it was necessary to develop a method for estimating or "hindcasting" a 30-year salinity time series for the river. This was accomplished through the use of a hydrodynamic model developed for the Loxahatchee River and estuary. Development, application and calibration of the hydrodynamic/salinity model is provided in **Chapter 4 – Methods** and in **Appendix E** of this document. Results of the simulated 30-year time series, for each vegetation monitoring site, are shown in **Appendix H**. Sample outputs of these data are shown in **Figure 28** for stations at river miles 10.2 and 9.2 respectively. From these time series basic statistical measures (mean, standard deviation, median, mode, 90th percentile distribution limits, and maximum daily salinity concentrations) were determined for each vegetation sampling site.



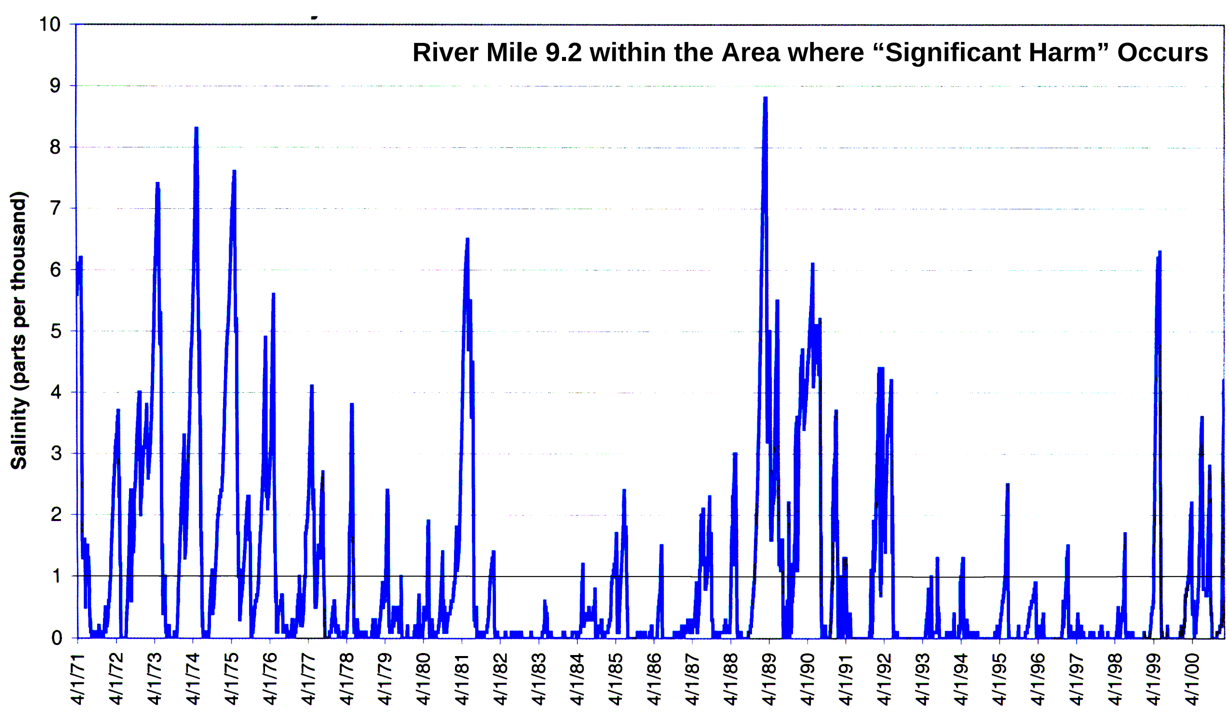


Figure 28. Simulated salinity time series generated from the hydrodynamic/salinity model developed for the Loxahatchee River showing the salinity regime (expressed as estimated mean daily salinity) at river miles 10.2 and 9.2, Northwest Fork of the Loxahatchee River.

The simulated salinity data were also analyzed in terms that are more relevant to the biology of the floodplain swamp community, i.e., the degree of exposure to low salinity conditions in terms of magnitude, event duration and time between events. It was assumed that some "threshold" level of salinity concentration, duration and return frequency exists that, when exceeded, causes an impact to a plant community. For example, along upstream segments of the Northwest Fork, a salinity event may occur at or above a specific threshold level for a number of days at a particular site. This event is followed by a period of time where freshwater conditions return and recovery from the salinity event occurs. To capture this salinity event-recovery cycle and the net effect it may have on the freshwater plant community, the long-term salinity data were examined in terms of salinity event duration (*Ds*) and elapsed time between events (*Db*) for a particular threshold.

Exposure to Different Salinity Concentrations at Particular Locations

Summary statistics were calculated for selected stations between river mile 7.8 and river mile 10.2, based on the output from the long-term modeling run (**Table 33**). The salinity average, standard deviation, upper maximum salinity and upper 90% confidence limit were determined for each station for the 30-year simulation period. The 90th percentile limit shows the level of salinity exposure that might be expected to occur during extreme events. For example, within the unharmed, healthy floodplain swamp community (river mile 10.2), salinities ranged from 0-3 ppt with a mean of 0.15. The upper 90th percentile of the salinity distribution at mile 10.2 was 0.65 ppt (i.e. 90% of the time, the average daily salinities at this location are below 0.65 ppt). At the stressed station (river mile 9.7), salinities ranged from 0-6 ppt with a mean of 0.5 and an upper 90 percentile limit of 1.7 ppt. At the significantly harmed station (river mile 9.2), salinity ranged from 0-9 ppt with a mean of 0.97 and 90% limit of 2.9 ppt.

Table 33. Summary statistics of estimated mean daily salinity concentrations for the 30-Year simulation period (1971-2001) for seven river vegetation sampling sites.

Site Name	River Mile	Salinity (ppt)				
		Mean	Standard Dev. (SD)	Upper 90% limit (Mean +1.28?SD)	Maximum Predicted
7-C (WQ Sta. #64)	7.8	6.2	5.2	13	21
8-B	8.4	3.7	4.1	8.9	18
WQ Sta. #65	8.6	2.8	3.4	7.1	16
8-D	8.9	1.8	2.6	5.2	14
9-B	9.2	1.0	1.6	2.9	9
9-C	9.7	0.48	0.94	1.7	6
10-B	10.2	0.15	0.39	0.65	3

Duration and Frequency of Exposure

Calculations of average salinity concentrations and ranges provided an estimate of the degree of exposure that vegetation communities may have experienced over time. These values, however, do not give an adequate indication of the amount of stress that occurs to a biological community. To provide a better description of exposure, the duration of a particular event and the amount of time that elapsed between events (recovery period) were determined. Although the duration of exposure and the amount of time needed for recovery to occur are unknown for these species, general criteria, for application at the community level, were inferred from available data. **Table 34** shows the mean duration of salinity events (*Ds*) and the mean time between salinity events (*Db*) at or above the selected threshold values for the modeled period.

Table 34. Salinity Event Duration (days) and Time Between Events (days), based on Simulated Salinity "Threshold" Levels, at Seven Sites along the Northwest Fork of the Loxahatchee River.

Site	River Mile	Mean Duration (*Ds*) and Elapsed Time Between (*Db*) Salinity Events									
		Salinity c 1ppt		Salinity c 2ppt		Salinity c 3ppt		Salinity c 4ppt		Salinity c 5ppt	
		Ds	*Db*	*Ds*	*Db*	*Ds*	*Db*	*Ds*	*Db*	*Ds*	*Db*
7C (WQ #64)	7.8	157	14	76	20	50	26	44	33	44	43
8B	8.4	83	23	49	39	52	62	48	77	45	94
WQ #65	8.6	67	30	68	70	58	85	56	111	40	124
8D	8.9	54	52	47	90	46	130	37	144	35	191
9B	9.2	55	143	46	207	45	344	41	504	29	612
9C	9.7	38	189	40	455	34	874	20	1800	22	5422
10B	10.2	31	576	22	2157	13	10899	0	10912	0	10912

For this analysis, the mean daily salinity level, as predicted by the model, was treated as a threshold rather than an average. For example, salinity at river mile 9.2 was plotted as a function of time, as shown in **Figure 28**. The number and duration of events when mean daily salinity equaled or exceeded 2.0 ppt and the elapsed time from one event to the next were determined. Salinity-exposure events increase in magnitude, occur more frequently, and last longer as one moves downstream. At the unharmed station 10B (river mile 10.2), salinity intrusion events with daily mean salinity above 1 ppt concentration and about 30 days duration, were estimated to occur once every 576 days (1.6 years). Daily mean salinities above 2 ppt occur for 22 days every 2157 days (5.9 years). Salinities as high as 3 ppt occurred once in the period of record (10,899 days or about 30 years). At the stressed station (river mile 9.7), daily mean salinities exceeded 1 ppt for approximately five weeks, twice per year; salinities above 2 ppt occurred for 40-days, less than once a year; and salinities exceeded 3 ppt for approximately one month every 2.4 years. At station 9B (river mile 9.2), where significant harm has been observed, salinities exceed 1 ppt approximately four months per year. Salinities above 2 ppt occurred for 46-day periods, about twice a year. Salinities exceeded 3 ppt for approximately 45 days every year (**Table 34**).

Effects of Flow from Lainhart Dam on Salinity Conditions in the River

Based on results from the hydrodynamic/salinity model a relationship between flow and salinity was established for each of the seven vegetation sampling sites located along the Northwest Fork. **Table 35** provides output from the model showing the amount of river flow at Lainhart Dam that is required to maintain mean daily salinity values at different points along the river. Details of the methods and graphical results of these analyses are provided in **Appendix H.** For example at river mile 9.2, a flow of approximately 35 cfs from the Lainhart Dam is sufficient to maintain an mean daily salinity of 1.9 ppt, whereas downstream at river mile 8.4, the amount of flow required to maintain the same average salinity is about 65 cfs (**Table 35**).

Table 35. Flow required from Lainhart Dam to maintain mean daily salinity levels at selected river miles.

Flow (cfs)	Mean Tide Salinity levels (ppt)							
	RM 10.2	**RM 9.7**	**RM 9.4**	**RM 9.2**	**RM 8.9**	**RM 8.6**	**RM 8.4**	**RM 7.7**
200	0.10*	0.10	0.10	0.10	0.11	0.12	0.13	0.21
150	0.10	0.10	0.11	0.11	0.12	0.15	0.19	0.39
100	0.10	0.11	0.12	0.14	0.20	0.34	0.47	1.5
85	0.10	0.12	0.14	0.18	0.29	0.54	0.87	2.3
65	0.11	0.17	0.2	0.34	0.66	1.3	1.9	4.2
55	0.1	0.3	0.4	0.6	1.1	2.0	2.8	5.5
50	0.14	0.30	0.5	0.8	1.3	2.3	3.2	6.2
45	0.2	0.4	0.7	1.1	1.8	2.9	4.0	7.1
40	0.19	0.57	0.9	1.4	2.2	3.5	4.7	8.0
35	0.3	0.9	1.3	1.9	2.9	4.4	5.7	9.2
30	0.34	1.15	1.8	2.5	3.6	5.3	6.7	10
20	0.78	2.34	3.3	4.2	5.6	7.7	9.3	13
10	2.01	4.67	5.9	7.2	8.8	11	13	17

* Values represent mean daily salinity levels, vertically averaged for the entire water column
Source: Output from the SFWMD Hydrodynamic Salinity Model

Flow vs. Salinity Relationships

When actual measured salinity data are graphed against measure flow across Lainhart Dam, a significant amount of "scatter," occurs (see **Appendix D** figures). Field measurements were collected primarily during low flow periods using a Hydrolab® Datasonde Model 3 electronic recording device. Salinity measurements were collected from a depth of about 1 meter above the river bottom at half-hour intervals over periods of 15-30 days (Dent and Ridler 1997). These data were later retrieved from the device, reviewed, and edited to record the maximum daily salinity value for each day.

In contrast, the model output represents a daily-averaged and vertically-averaged concentration. Because of these differences, it is not surprising that the observed frequency distribution of low-flow events over Lainhart Dam, as presented in **Table 24,** does not agree exactly with the frequency distribution of salinity events derived from the long-term model, as shown in **Tables 34** and **35.** Based on the observed data in **Table 24**, for example, under current (1990 to 2001) conditions, flows drop below 35 cfs for 15 days every two months. This is somewhat comparable to the prediction that salinities will exceed 2 ppt for 46 days every 6.8 months at station 9.2 (**Table 35**), since the latter estimate approximately represents a three-times longer time span over which the data were aggregated (6 months vs 2 months).

Comparison between Modeled Data and Observed Data

Differences between model and observed results also occur due to the built-in response time of the model to changes in flow. In addition, there is relatively good daily flow data from only one of the structures and tributaries that provide flow to the river. Discharges from other tributaries, on average, seem to be relatively predictable percentages of the flow from Lainhart Dam. However, they may vary considerably on a daily basis due to local conditions, resulting in a wide range of salinity values associated with a particular flow value for Lainhart Dam. The salinity data are of limited duration and are often incomplete.

Due to the limited number of continuous data sets available, salinities calculated from the calibrated and verified model were used as the basis to analyze long-term trends. The model provides a more consistent estimate of salinity, can account for some of the known sources of variability in the data (tidal cycles), and can be used to simulate how the system would perform under a wider range of hydrologic conditions that better represent the inter-annual patterns and cycles of flood and drought that occur in South Florida. However, the model may not provide a very accurate representation of conditions in the river at any particular point in time. The assumption was made that such errors are random so that model does provide accurate predictions of salinity averages and trends over long time periods.

The peer review panel cited a concern that systematic errors may have been incorporated in the analysis, due to structural or management changes in the system that have occurred during the period of record. Such alterations may have affected the basic flow-salinity relationships, and thus could bias our long-term flow and salinity estimates at particular stations. An additional analysis was therefore conducted to compare salinity vs flow relationships at different points along the river, using data collected from different time periods (see **Figure 29**).

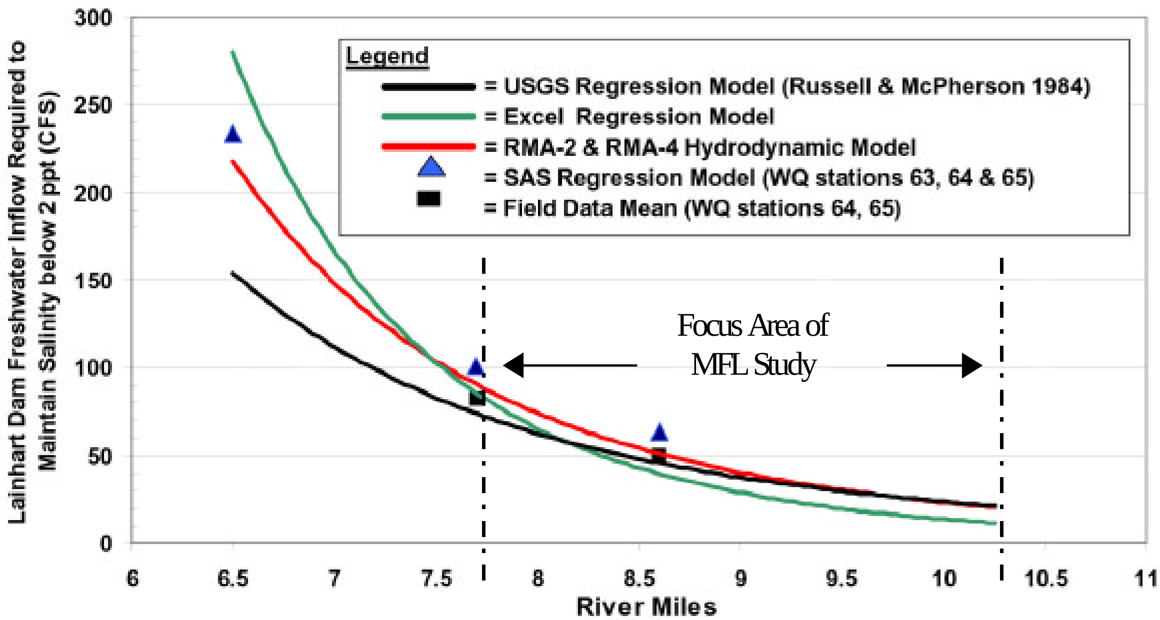


Figure 29. Comparison of Hydrodynamic Model with Regression Analyses of Field Data.

The data generated by the hydrodynamic/salinity model, based on the 30-year period of record, were compared to data collected in the early 1980s by the USGS (Russell and McPherson 1984) and two different statistical analyses of data that were collected in the late 1980s through 1995. Data collected during the early 1980's (Russell and McPherson 1984), represents a period prior to a number of structural changes that occurred in the late 1980's. The results of this comparison (**Figure 29**) indicate that the flow-salinity relationships predicted by the model are similar to those derived directly from field data, using three different analytical methods. There was especially good agreement among the methods in the upstream portion of the river, from river mile 7.8 to river mile 10.2, the area of primary concern for this study. It was therefore concluded that recent structural changes in the river watershed have not had a significant effect on flow-salinity relationships in the river.

Summary of Technical Results

- Long-term flow records for the Loxahatchee River indicate that average flows during the dry season (October 16-May 14) are 70 cfs. During extremely dry conditions, such as those that existed during the 1980-81 and 1989-90 droughts, dry season flows from Lainhart Dam averaged between 26-35 cfs (**Table 24**).
- Examination of the flow record for Lainhart Dam from 1977 to 2001 indicates that increased rainfall and improvements to the G-92 structure in 1987, have increased average flow to the river from 55 cfs to 106 cfs (**Figure 19**). Also the occurrence of flows below 35 cfs has been reduced from 34 percent of the time (1971-1989) to 25 percent of the time (1990-2001) (**Table 25**). These changes can be attributed to a combination of changes in weather patterns and improved management practices.
- In spite of thee benefits, there has been little or no improvement in flows to the river during very dry periods. Review of flow duration curves developed for the Lainhart Dam shows that about 10% of the time, flows are reduced to about 14 cfs over the 30 year period of record (**Figure 20**).
- Results of a river vegetation survey identified six woody vegetation species (red maple, pop ash, dahoon holly, pond apple, Virginia willow and red bay), which predominantly occur in fresh water (**Table 30**), as useful indicators of long-term salinity changes within the river. These six species were selected as indicators for the Valued Ecosystem Component for the Northwest Fork.
- Results of vegetation surveys indicated that a unharmed, healthy floodplain swamp community exists and river mile 10.2, a "stressed" community exists at river mile 9.7, and those communities that remain at river mile 9.2 has been significantly harmed (**Tables 31-33, Figure 26**).
- Comparison of vegetation along the river based on aerial photography, indicates that floodplain vegetation in the upstream areas of the river changed significantly between 1940 and 1995 (**Appendix B**). Results presented in **Chapter 2** and **Figure 31** suggest that there was very little change in river vegetation patterns between 1985 and 1995 and that the improved hydrologic conditions may have stabilized or slowed the trend of river floodplain degradation.
- Since long-term salinity records did not exist for the each vegetation site sampled along the Northwest Fork of the river, a hydrodynamic/salinity model was used to simulate a long-term (30 years) time series of salinity conditions at each site. For each time series, descriptive statistics (mean, standard deviation, 90th percentile, maximum) were developed to characterize salinity regimes at each vegetation sampling site (**Table 34).**
- The data were also expressed in terms of the amount of time that salinities of different levels occurred at each station and the return frequency between salinity exposure events during the 30 year simulation (**Table 35**).
- Results showed that at river mile 10.2 (within the unharmed, healthy floodplain swamp

community) salinities ranged from 0 up to 3 parts per thousand (ppt) with a mean salinity of 0.15 ppt and a 90th percentile of 0.65 ppt during the 30 year simulation. These data indicate that this portion of the river is a freshwater system except during low flow periods when mean daily salinities may exceed 2 ppt for 20 days every six years. Salinity exceeded 3 ppt only once, for a 13-day period, during the 30-year simulation period.

- Downstream at river mile 9.7 (the stressed floodplain swamp community) daily mean salinity levels ranged from 0 up to 6 ppt with a mean salinity of 0.5 ppt and 90th percentile limit of 1.7 ppt during the 30 year simulation. This represents about a three-fold increase in mean salinity as compared to the healthy floodplain swamp community located at river mile 10.2. Salinities at river mile 9.7 exceeded 2 ppt for an average of 40 days, once every 1.25 years.
- Further downstream at river mile 9.2 (the significantly harmed site) salinity levels ranged from 0 to 9 ppt with a mean salinity of 0.97 ppt and 90th percentile limit of 2.9 ppt recorded over the 30 year simulation. Overall, this represents about a six-fold increase in mean salinity as compared to the site at river mile 10.2. At this site, salinity levels exceeded 2 ppt for an average of 46 days, with a return interval of about seven months.
- A flow/salinity relationship was established for each of the seven vegetation sampling sites, based on output of a hydrodynamic/salinity model (**Table 35**). These data show the amount of flow (as measured at the Lainhart Dam) required to maintain average salinity conditions at different points located along the river. These data may also be used to estimate the flows required to maintain desired salinity conditions at different locations on the Northwest Fork.

Application of the River Vegetation/Salinity (SAVELOX) Model

Using the vegetation survey results and the salinity time series generated from the hydrodynamic model, correlation analyses were used to examine vegetation trends relative to salinity event duration. From these data, a river vegetation/salinity model (SAVELOX) was developed using an empirical approach to extrapolate vegetation parameter response given a set of long-term salinity conditions (see **Chapter 4**). The model formulas were based upon the correlation between measured vegetation parameters (i.e. abundance, height of adults, canopy cover, etc.) and a calculated salinity ratio *Ds/Db* at those sites where both computed salinity and vegetation survey data existed.

SAVELOX Model Results

Relationships between vegetation trends and long-term salinity conditions along the Northwest Fork were determined (**Table 36**) and expressed as relational formulas that were the basis for the SAVELOX model. A predicted value for a given vegetation parameter was calculated from the following user input: 1) selection of a mean salinity event threshold ($\geq$1 ppt, $\geq$2 ppt, or $\geq$3 ppt); and 2) long-term mean salinity event duration and mean time between salinity event for a location along the Northwest Fork. The model output is a predicted value for a vegetation parameter at a location along the Northwest Fork. Model output was verified using additional intermediate site vegetation data collected along the Northwest Fork (V-1, V-2, V-3, etc., **Figure 16, Chapter 4**) which were not used in development of the formulas.

Table 36. Estimated Salinity Event Ratio (*Ds/Db*) at a 2 ppt Threshold Associated with a Decline of Measured Freshwater Vegetation Parameters.

Species	**Abundance Index**		**No. of Adults Per Site**[4]		**Canopy Coverage (Adults)**		**Mean Height (Adults)**		**Mean DBH (Adults)**		**No. of Juveniles Per Site**[4]	
	Dec[1]	**NP**[2]	**Dec**	**NP**	**Dec**	**<5%**	**Dec**	**NP**	**Dec**	**NP**	**Dec**	**NP**
Bald Cypress	0.28	5.00[5]	0.13	5.00[5]	0.13	0.38	N/A	5.00[5]	N/A	5.00[5]	0.13	0.52
V. Willow	0.13	0.13	0.13	0.28	N/A	N/A	N/A	0.28	N/A	N/A	0.13	0.28
Dahoon	0.13	0.52	0.13	0.33	N/A	N/A	0.13	0.33	0.13	0.33	0.13	0.28
Pop Ash	0.28	0.52	0.28	0.52	0.13	0.28	0.28	0.52	0.13	0.52	0.28	0.28
Pond Apple	1.26	1.26	0.28	1.22	0.13	0.60	0.28	1.22	0.28	0.60	0.28	0.28
Red Maple	0.13	0.75	0.28	0.28	0.13	0.28	0.28	0.28	0.13	0.28	0.13	0.13

[1] Dec = Most downstream point of the river where the vegetation parameter (Ds/Db) was observed to decline below background levels; where a drop in the value was first noted (moving from upstream to downstream)
[2] NP = Most downstream point of the river where the vegetation parameter was either no longer present, where the value first reached zero, or where there were no individuals found (moving from upstream to downstream)
[3] N/A = not able to be determined from the data
[4] Based upon combined totals from both plots surveyed at a site
[5] Indicates an estimated value

Table 36 shows the salinity ratio threshold associated with a decline in or a value of zero for each measured vegetation parameter for several key species. Using the SAVELOX model, this information can be expanded to include salinity event magnitude (threshold $\geq$1 ppt, $\geq$2 ppt, or $\geq$3 ppt), duration, frequency, location (expressed as river mile) and the corresponding estimated minimum flow over Lainhart Dam required to keep salinity below the threshold value. An example of SAVELOX model results are shown for red maple in **Table 37**.

Table 37. Output of the SAVELOX Model: Mean Salinity Event $\geq$2 ppt Duration (days), Mean Time Between Events (days), and Flow (cfs*) associated with community vegetation parameter changes in Red Maple (*Acer rubrum*).

Red Maple					
Vegetation Parameter	**Change in Parameter**	**River Mile**	**Event $\geq$2 ppt Duration (days)**	**Event $\geq$2 ppt Frequency (days)**	**Lainhart Flow (cfs)***
Abundance Index	Decline[1]	9.7	42	320	30
	Not Present[2]	8.7	60	76	65
Number of Adults Per Site	Decline	9.2	44	157	40
	Not Present	9.2	44	157	40
Canopy Coverage (Adults)	Decline	9.7	42	320	30
	Not Present	9.2	44	157	40
Mean Tree Height (Adults)	Decline	9.2	44	157	40
	Not Present	9.2	44	157	40
Mean DBH (Adults)	Decline	9.7	42	320	30
	Not Present	9.2	44	157	40
Number of Juveniles Per Site	Decline	9.7	42	320	30
	Not Present	9.7	42	320	30

CFS = cubic feet per second

1 Decline = Most downstream point of the river where the vegetation parameter was observed to decline below background levels; where a drop in the value was first noted (moving from upstream to downstream)
[2] Not Present = Most downstream point of the river where the vegetation parameter was either no longer present, where the value first reached zero, or where there were no individuals found (moving from upstream to downstream)

Based on these model results and outputs, it is possible to predict the future distribution of the six VEC species along the Northwest Fork, based on the following:

- The model provides the capability to analyze future water management scenarios that predict hydrologic conditions and flow patterns in the river to determine the resulting salinity regime.

- Based on empirical data derived from healthy stressed and damaged plant communities that presently exist on the river, the model can be used to predict the downstream distribution limits (in river miles) of the healthy freshwater floodplain swamp community or any of its component species.
- In addition, it can be used to determine areas where the freshwater swamp community or its component species will be stressed, and locations where significant harm occurs to this community.
- The model can also be used to predict what flow conditions are necessary to protect or restore these species and the floodplain community.

DEVELOPMENT OF RESOURCE PROTECTION CRITERIA.

Results of the quantitative data from the river vegetation survey have shown that a relatively non-impacted, "healthy", sustainable floodplain swamp community exists at river mile 10.2. Results of the semi-quantitative sampling indicate that these plant communities remain healthy as far downstream as river mile 9.9.

It should be noted that although there is a direct correlation between presence, abundance and health of "freshwater" forest species and distance from the inlet and that there is a corresponding inverse correlation with salinity concentrations in the river, these correlations do not prove a cause-effect relationship. Specific data on salt tolerances of these six species would be required to establish that salt water exposure was responsible for changes in vegetation along the river channel. Such evidence has not yet been attained and District staff have had to rely on general information that is provide in the literature such as that shown in **Table 29.** Nevertheless, it appears, based at least on empirical evidence from this particular river system, that salinity can at least be considered as a surrogate for stress factors that presently limit the downstream distribution of the floodplain swamp community along the Northwest Fork.

The salinity conditions that occur at river mile 10.2 are essentially those of a freshwater system, except during dry periods when mean daily salinities may increase up to 2 ppt (**Figure 28**). Model simulations show that such elevated salinity conditions have occurred, on average, for periods of about 20 days, once every six years (**Table 34)**. Review of these data indicate that salinity conditions that exist at river mile 10.2 provide a viable and sustainable freshwater floodplain swamp community. More strenuous conditions in terms of magnitude, frequency or duration of salinity exposure, such as those experienced downstream at station 9.7, lead to stress of the freshwater swamp community. Exposure to more severe salinity conditions, such as those that occur at station 9.2, have resulted in significant harm to the floodplain swamp community.

Although there may be a basis to define a "minimum" flow for the river based on a "maximum allowable salinity event," the ability of plant communities to survive such periodic impacts depends on the health of the community prior to exposure. Since the resource to be protected is a freshwater plant community, the preferred condition would be to not allow any salt water to enter this system. If the community is healthy, by virtue of not having been exposed to salt water for a long period, it can tolerate occasional salinity stress. Likewise if the stress period is followed by a long period when no salt is present, the community can effectively recover.

By contrast, if salinity stress occurs frequently, the community will become increasingly damaged, will not have time to recover and will continue to degrade. This progressive damage may occur due to the direct effects of salt toxicity and/or secondary effects such as a) reduced resistance to insects and diseases, b) competition by more salt-tolerant species such as mangroves, and c) reduced growth and reproductive success. In summary, a robust freshwater floodplain swamp community that has a history of non-exposure to salinity intrusion is better able to survive an occasional increase in salt content than a community that has been stressed by frequent exposure to elevated (although perhaps non-lethal) salinity conditions.

Repeated low-level salinity stress may be sufficient to prevent seed germination and/or to kill newly-sprouted seedlings and saplings of freshwater species without killing the adult plants. In this case, the plant "community" may continue to exist for some time, but without recruitment of new individuals. In this case, the community is not sustainable and will eventually die out and be replaced by saltwater-tolerant species.

The MFL is based on the amount of flow that is required to protect a primarily freshwater system from significant harm when exposed to short-duration, infrequent events that have limited allowable salinity concentrations. Several different salinity criteria were examined as a basis to ensure that the resource was adequately protected. The purpose of this effort was to determine parameters that could be effectively measured in the field, derived from field data or from model simulations and that could be empirically linked to resource impacts.

Based on the analyses and considerations described above, SFWMD staff conclude that to continue to protect the habitat values, species composition, and canopy structure of the existing healthy floodplain swamp community that exists at station 10B (river mile 10.2) and extends downstream to river mile 9.9, average salinity conditions, as determined by the model, should be maintained at or below 0.15 ppt. Daily mean salinity should not be allowed to exceed 1 ppt more than 5 percent of the time (40 days per year), 2 ppt more than 1 percent of the time (30 days in four years) and should not exceed 3 ppt more than 20 days in 10 years (see **Tables 33 and 34).** This indicates that to provide adequate protection for the resource, a range of flow, duration and frequency criteria can be defined for this station as represented in the first line of **Table 38.** A number of previous authors have identified the 2 ppt threshold as being an effective indicator of saltwater contamination because this concentration is significantly higher than background concentrations of salts that might be derived from other sources such as runoff or mineralized groundwater flow. Previous studies have shown generally good correlation between measured values and the locations of the 2 ppt isohaline contours that were predicted by the hydrodynamic model for this river system.

Although a daily mean concentration of 2 ppt is easily estimated from the hydrodynamic/salinity model, it is not clear how this predicted mean salinity relates to the actual range of salinity conditions that may be experienced at a particular location during a 24-hour period. The SFWMD is in the process of upgrading the Loxahatchee River hydrodynamic model to a three dimensional model and establishing a more effective monitoring program in the river to address this issue.

Table 38. Various Salinity parameters that can be used to protect the resource.

River Mile	Approximate Flows (cfs)* needed to maintain salinity concentrations:				
	Mean = 0.15 ppt	Mean = 0.3 ppt	Salinity ≥ 1ppt Not to exceed 31 days/1.6 yr**	Salinity ≥ 2ppt Not to exceed 22 days/5.9yr	Salinity ≥ 3 ppt Not to exceed 14 days/10yr
10.2	50	**35**	20	10	5
9.7	80	50	**32**	25	15
9.2	100	70	47	**35**	**22**
8.9	140	85	60	42	**27**
8.6	150	120	75	55	42
8.35	200	130	80	65	52

* Flows obtained from Table 35 for a given salinity value at a given station location

** Occurrence frequency and duration were obtained from Table 34: for example for 1ppt salinity at station 10.2 *Ds* = 31 days and *Db* = 576 days or 1.6 years; Likewise at 2-ppt salinity, *Ds* =22 days and *Db*=2157 days or 5.9 years

Previous studies have also shown that salinity concentrations in the river are stratified (i.e. low salinity or fresh water is present at the top of the water column and higher salinity water is located at the bottom). Since the two-dimensional model represents a "vertically averaged" salinity, a predicted daily average value of 2 ppt at a particular point in the river is assumed to represent salinity values that range from perhaps 4 ppt at the bottom of the river channel to near fresh water conditions at the surface. Also, since the salinity represents a daily average, there may be a considerable variation at a given point between high tide and low tide conditions, so that a daily average bottom salinity of 4 ppt could potentially represent a low tide bottom salinity of 0 ppt and a high tide bottom salinity of 8 ppt. Salinities of above 7 ppt have been measured in the river upstream of mile marker 10 during an extreme drought condition (Russell and McPherson 1984). Modeling results presented in this study indicate that average salinities as high as 3.5 ppt may occur at this location during an extreme low flow condition.

Data from this study suggest that the 2 ppt isohaline (representing a maximum of perhaps 4 ppt salinity at the bottom of the water column) may have particular relevance to the protection of the freshwater floodplain swamp community. This level is exceeded only about once every 6 years in healthy communities such as those documented at river mile 10.2. This low rate of occurrence is reflective of historical regional rainfall patterns and based on model results is apparently sufficient enough to allow the community to recover to a healthy condition between events. Salinity exposure is sufficiently infrequent enough to allow seeds to germinate successfully and grow beyond the most sensitive life stages.

In contrast, a daily mean salinity of 2 ppt is exceeded about once every year in the "stressed" communities (river mile 9.7), and is exceeded about once every 160 days in communities that have experienced significant harm (river mile 9.2) (**Table 34).** These relatively low levels of exposure are apparently sufficient enough to result in loss of canopy cover, reduced growth, prevention of successful seed germination and subsequent survival of VEC indicator species. Data collected in this study, and information compiled from literature reviews of the salinity tolerance of freshwater vegetation also suggest that seedlings and saplings characteristic of freshwater floodplain swamp communities may be more acutely sensitive to salt concentrations between 3 and 6 ppt. This sensitivity is indicated by a loss of saplings and seedlings of VEC species at river mile 9.7. Exposure to mean daily salinities above 3 ppt occurs approximately once every 2.5 years (34 days out 29 months) at river mile 9.7.

Definitions of No Harm, Stressed and Significant Harm

Based on results of the above field studies, modeling, and data analyses, the following criteria were developed to define a non-impacted, healthy, sustainable floodplain swamp community (the "No Harm" condition) for the Northwest Fork of the Loxahatchee River as well as various other degrees of impacts -- "stressed" and "significant harm" -- as discussed below.

No Harm

The area of the river that characterizes the "no harm" condition is typified by those vegetation communities that were documented in quantitative studies to occur at river mile 10.2.

- All six VEC indicator species are present within the floodplain swamp community.
- The floodplain swamp consists of a high canopy of bald cypress and mixed hardwoods, approximately 35 - 60 ft. in height; a subcanopy of mixed hardwoods, 15-30 ft. in height, and an understory of more than 30 species of vascular plant species.
- Seedlings, saplings and adults of the six VEC species are present, indicating that the community is reproducing and sustainable.
- Results showed that at river mile 10.2, located within the unharmed, healthy floodplain swamp community, mean daily salinity levels ranged from 0 up to 3 parts per thousand (ppt) with a mean daily salinity of 0.15 ppt and a 90th percentile limit of 0.65 ppt during the 30 year simulation. This portion of the river is essentially a freshwater system except during low flow periods when salinities may exceed 1 ppt for 30 days once every two years, and 2 ppt for about 20 days, once every six years.

Stressed

At river mile 9.7, the floodplain swamp has been identified as "stressed" in response to elevated salinity concentrations experienced during low flow conditions. This community is characterized as follows:

- Most of the six VEC indicator species are present, however they are reduced in abundance, tree height, and trunk diameter.
- The number of other plant species is reduced, especially the number of herbaceous species.
- A measurable change in the floodplain forest canopy structure is observed
- Although seedlings and saplings are present, they are reduced in number.
- The long-term salinity record at river mile 9.7 shows that during drought periods this area of the river has been exposed to more frequent occurrences of saline conditions as compared to the "no harm" condition.

- Daily mean salinity levels predicted by the model ranged from 0 up to 6 ppt with a mean salinity of 0.5 ppt and 90th percentile limit of 1.7 ppt during the 30 year simulation. This represents about a three-fold increase in salinity as compared to river mile 10.2. At river mile 9.7 salinity levels exceeded 1 ppt for about 40 days, twice a year, and exceeded 2 ppt about 40 days about once a year.

Significant Harm

Significant harm is defined as *the temporary loss of water resource functions which result from a change in surface or ground water hydrology, that takes more than two years to recover, but which is considered less severe than serious harm* (Chapter 40E-8, F.A.C.). Based on the data presented in this report, significant harm has occurred when:

- Two or more of the six VEC species are no longer present within the floodplain swamp landscape. Based on the results of the river vegetation survey, three of these key species (red bay, Virginia willow, and red maple) are no longer present at river mile 9.2.
- The total number of species present is reduced by about one-third as compared to values recorded upstream of river mile 10.2.
- The floodplain swamp high canopy is no longer present and has been replaced by a low canopy dominated by saltwater tolerant mangroves.
- Seedlings of the six VEC species are no longer present indicating this area can no longer support a reproducing floodplain swamp community.
- At river mile 9.2, daily mean salinity levels ranged from 0 up to 9 parts per thousand (ppt) with a mean salinity of 0.97 ppt and a 90th percentile limit of 2.9 ppt during the 30 year simulation. Overall this represents about a six-fold increase in mean salinity as compared to river mile 10.2. At this site salinity levels exceeded 1 ppt for about 55 days, twice a year and exceeded 2 ppt for 45 days for about once a year.
- Based on these data, river mile 9.2 represents the point in the river where significant harm occurs. Upstream of this point both healthy and salinity “stressed” floodplain vegetation communities continue to exist. Downstream of river mile 9.2 the freshwater dominated floodplain swamp and its associated high canopy are no longer present and have been replaced by saltwater tolerant red mangrove communities with a few remaining stands of bald cypress and cabbage palm trees.

Proposed Minimum Flow Criteria

Basis of Proposed Criteria

Protection from Harm

Based on the results of this study, the flow/salinity regime recorded upstream at river mile 10.2 currently supports an unharmed, healthy, sustainable floodplain swamp community. It is the District’s intention to reproduce this salinity regime downstream at river mile 9.2, the point in the river where significant harm has been shown to occur. Using relationships developed from output of a hydrodynamic/salinity model (**Table 38),** a flow regime is needed that will provide essentially freshwater conditions (long-term average salinities of 0.1 to 0.2 ppt) at river mile 9.2.

Protection from Significant Harm

However during very dry periods, Lainhart Dam flows may be substantially reduced as upstream sources are depleted. Under such dry conditions, sufficient flow should be provided to the river to prevent the salinity regime at river mile 9.2 from exceeding 2 ppt for any longer time than has occurred within the "healthy" floodplain swamp community. Such events should not last for more than 20 consecutive days duration, and not occur more often than once every six years, in order not to exceed the salinity regime recorded upstream at river mile 10.2. Review of the flow/salinity relationships shown in **Table 38** indicates that in order to maintain mean daily salinity below 2 ppt at river mile 9.2, the Lainhart Dam needs to provide a minimum flow of at least 35-cfs to the Northwest Fork of the river.

In summary, proposed minimum flow criteria for the Loxahatchee River and Estuary were based on the following:

- Results of this study indicate that sufficient quantities of fresh water from the Lainhart Dam are required to protect the floodplain swamp and associated bald cypress habitat against significant harm. This community has been identified as a valued ecosystem component (VEC) for the Wild and Scenic portion of the Northwest Fork of the Loxahatchee River.
- Research conducted by the SFWMD identified locations on the river where both "healthy" and "stressed" floodplain communities exist (at river miles 10.2 and 9.7, respectively), and identified downstream locations where significant harm to this community is presently occurring (river mile 9.2).
- In order to protect the remaining healthy and stressed floodplain swamp community and the area that currently is experiencing significant harm, sufficient flow should be provided from the Lainhart Dam whenever possible to maintain essentially freshwater conditions in the river upstream of river mile 9.2.
- Modeling results indicate that flows below 35 cubic feet per second from Lainhart Dam cause salinities in excess of 2 ppt to occur at sites where remaining stressed and harmed plant communities exist along the Northwest Fork of the Loxahatchee River. Frequent exposure to salinity levels in excess of 2 ppt was associated with damage to freshwater vegetation.
- During periods of regional drought, due to the limited storage capacity of the basin, it may not be possible to maintain fresh water conditions at river mile 9.2 or to meet the 35-cfs flow criterion at all times. In order to prevent damage or stress from occurring to the floodplain swamp community at river mile 10.2 and significant harm from occurring at river mile 9.2, freshwater flows should not decline below a discharge rate of 35 cfs at the Lainhart Dam for a period of more than 20 consecutive days, more often than once every six years.

Technical Criteria

Based on the above information, SFWMD staff propose the following MFL criteria for the Northwest Fork of the Loxahatchee River:

A MFL violation occurs within the Northwest Fork of the Loxahatchee River when an exceedance, as defined herein, occurs more than once every six years. An "exceedance" occurs when Lainhart Dam flows to the Northwest Fork of the Loxahatchee River decline below 35 cfs for more than 20 consecutive days within any given calendar year.*

* A flow of 35 cfs is equivalent to a recorded stage of 10.68 ft. NGVD as measured upstream of the Lainhart Dam at the SFWMD gage named "LNHRT W".

Effects of the Proposed MFL on Salinity Conditions in the Estuary

To assess the potential impact that the proposed MFL may have on estuarine resources, the following evaluations were based on a literature review and a review of output from the hydrodynamic/salinity model.

Although the extent of the oligohaline zone is reduced considerably in the Loxahatchee River during very dry periods, low-salinity conditions still persist within the river for several miles downstream of the Masten Dam within the Wild and Scenic portion of the River. Loss of a year class of important species is not likely to occur. With the proposed MFL of 35 cfs in place, and the projects to achieve this flow constructed, flows to the river will remain at or above 35 cfs for about 94% of the time (see **Table 43**, Chapter 6). The effects of a 35 cfs flow on the estuary have been previously analyzed as shown in **Appendix F**. Flows in the range from 30-60 cfs were sustained during 1981 (Russell and McPherson 1984) and salinity conditions in the estuary were measured at high and low tides (see **Figure F-3** in **Appendix F**). Although this was not a rigorous study of the effects of such discharges, it provides an indication of likely effects. These results also showed that, in general, salinities throughout most of the estuarine portion of the system were in the range of 30-35 ppt on the bottom and at high tide. During low tides, salinities at the top of the water column in the Northwest Fork and on the bottom in the upper reaches of the Northwest Fork declined to 25-30 ppt. Although it was not measured in the report, observations by District staff and local citizens, indicate that under conditions of low discharge and daily tidal exchange, water clarity generally improves throughout the estuary. Such conditions are beneficial for seagrass communities that live in the central embayment and, at the same time, do not cause undue harm to the oyster communities that form reefs and live on mangrove roots in the Northwest Fork in the vicinity of river mile 6.6 by the JD Park boat ramp.

Estuary Resources that need Protection

An effort was made to characterize the significant biological resources that exist in the estuarine portion of the Loxahatchee system (Chapter 2 pages 26-36). These included primarily mangrove swamp communities, other saltwater marsh vegetation, seagrasses and marine algae, fishes, macroinvertebrates and manatees. Our present (very limited) understanding of the relationships between these system components and freshwater inflows was also described. The Loxahatchee estuary covers the entire range from a primarily marine environment near the inlet and into the central embayment to a completely freshwater environment in the upper reaches of the Northwest Fork.

Effects of the Proposed MFL on Estuarine Organisms

More detailed studies of estuarine organisms and their relationships to freshwater discharges are warranted. Presently the District has engaged a fisheries expert on estuarine fish, to perform a more detailed assessment of estuarine resources in the Loxahatchee River and develop a recommended species list, monitoring, and research needs, to address these concerns.

From the information reviewed it appears that the MFL proposed for the Northwest Fork should not have any significant adverse effects on the estuary and may in fact be beneficial rather than harmful to these resources. In general, species diversity of benthic communities increases as a function of proximity to the inlet (Dent et al., 1998). Under very low flow conditions (see **Appendix F, Figure F-4**), most of the estuary becomes a marine system (30-35 ppt salinities). If these low flow/high salinity conditions persist for several weeks or months, seagrass communities may tend to expand upstream, providing more habitat and food for marine and estuarine fishes and invertebrates, additional stabilization of soft mud bottom communities and provide additional food for manatees. There may be some mortality occurring in oyster communities at the upper end of the Northwest Fork and some associated recruitment occurring further upstream.

The upper reaches of the Northwest Fork still contain extensive areas of habitat suitable for oysters, as well as oligohaline and freshwater habitat. Extreme fluctuations in salinity, associated with periodic low flow events, are not conducive to the development of extensive oyster communities. Oysters are very beneficial to coastal estuaries such as the Loxahatchee River because they tend to stabilize bottom sediments, filter suspended materials from the water column and provide an extensive surface area and substrate for colonization of other organisms.

The proposed MFL is anticipated to improve over current conditions in the estuary by providing for a more extensive and stable oligohaline zone (less than 5 ppt salinity) upstream in the river between river miles 9.2 and 8.5 or so, than occurs at present. Conditions that are more conducive to the growth of oysters on mangrove roots and the formation of oyster reefs or bars (15-25 ppt salinity) are expected to occur in the vicinity of river mile 6 along the river. At the same time, these flows are not expected to adversely affect the marine communities in the central embayment, especially the Johnson' seagrass community that exists near the railroad bridge.

Effects of Proposed MFL on Floodplain Hydrology

Floodplain Transect Analyses To assess the potential effects of the proposed MFL on the upstream floodplain swamp, District staff conducted the following analyses which are provided in detail within Appendix N. District staff utilized a series of soil elevation and surface water measurements within the Wild and Scenic portion of the Loxahatchee River (Figure 30). Field surveys were conducted by SFWMD survey staff at four transect locations from December 1983-April 1984. These data provided measured soil elevations (feet NGVD) across each floodplain transect (SFWMD survey staff field notes). Transects 1 and 2 were located between Indiantown

Rd. and the Florida Turnpike/I-95 bridges. Transects 4 and 5 were located between the Florida Turnpike/I-95 bridges and the Trapper Nelson's interpretive site located in Jonathan Dickinson State Park (**Figure 30**).

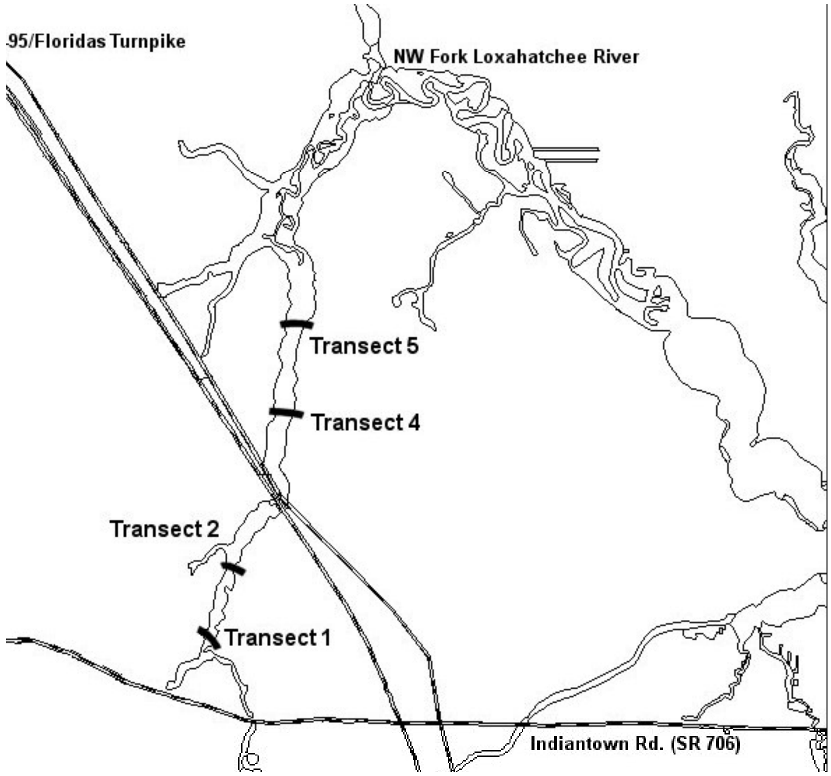


Figure 30. Location of the transect sites along the upper NW Fork of the Loxahatchee River.

In addition to the soil elevation measurements, stage recorders were placed at each transect to record daily water stage data from 1984-1990. These data were extracted from the District's DBHydro database and utilized in these analyses. The soil elevation data was placed into an Excel spreadsheet to develop profiles of each transect. (see **Appendix N, Figures N-2a** to **N-2d).**

Transect survey results are presented in **Table 39**. Results show that the mean floodplain elevations ranged from 9.9 ft. to 2.3 ft NGVD from Transect 1 downstream to Transect 5 indicating an elevation difference of about 7 feet. Similar results are shown for the river channel where the elevation change between upstream and downstream sites was about 6 ft. (**Table 39**).

Table 39. Transect Lengths and Approximate Floodplain Elevations (NGVD) at each Transect

	Transect 1	Transect 2	Transect 4	Transect 5
Total Transect Length (ft)	470	560	520	670
– Upland (ft)	30	90	90	20
– Floodplain Swamp (ft)	360	430	400	580
– River Channel (ft)	80	40	30	70
Floodplain-Upland Ecotone (NGVD)	12.4 – 14.6	8.0 – 11.9	4.8	2.1 – 5.6
Floodplain-Channel Ecotone (NGVD)	8.2	6.9	2.7	2.0
Channel Bottom (NGVD)	1.4	3.2	-3.2	-2.2
Mean Floodplain Elevation (NGVD)	9.9	8.2	4.0	2.3

In contrast, elevations recorded within the upland-floodplain swamp ecotone between opposing sides of the river at three of the transects were inconsistent and highly variable. This may be related to the magnitude of freshwater seepage available from upland areas flanking the floodplain. Review of transect profiles as illustrated in the example provided in **Figure 31** indicates the floodplain is not flat, but undulates along an elevation that varies between 1.0 to 1.5 ft. from the river channel to the edge of the floodplain.

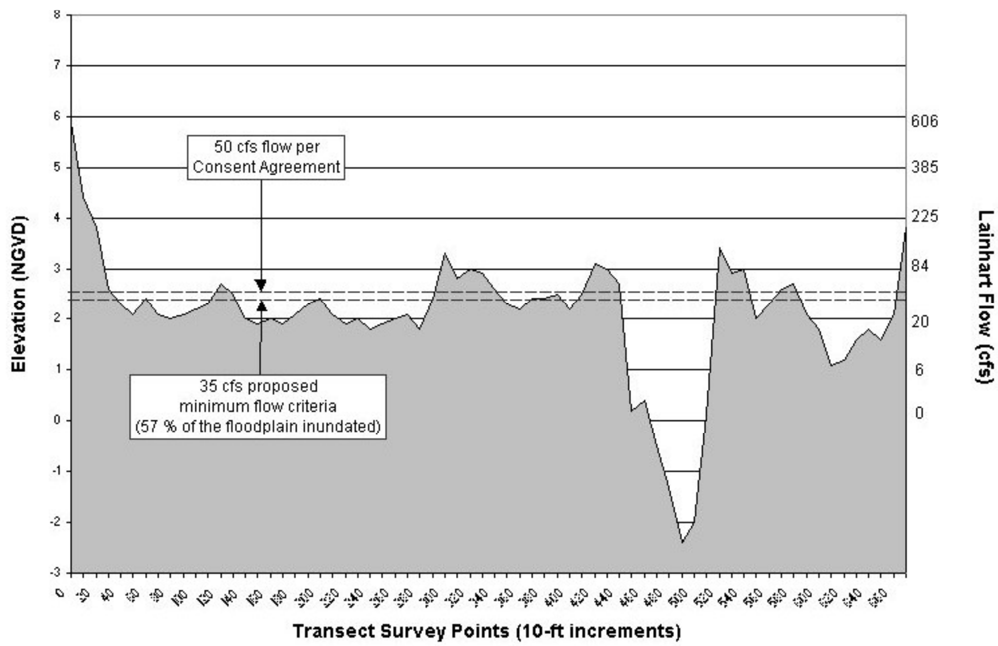


Figure 31. Transect 5 profile across the floodplain, upper NW Fork of the Loxahatchee River.

Figure 32 provides a hydrograph of surface water levels recorded along each transect from 1984-1990 as well as Lainhart Dam flows for the same time period. From a comparison of the mean difference between daily stage measurements recorded at each transect and those recorded at Lainhart Dam, a relationship was developed (**Table 40)** between Lainhart Dam stage and water level stages recorded at each transect. Daily stage measurements at Lainhart Dam were also used to calculate flows. These daily stage (flow) measurements and average transect elevation data (**Table 40**) were used to provide an estimate of the percent of the floodplain that could be expected to be inundated at a given flow magnitude. This relationship is shown in **Table 40.**

Table 40 . Mean (standard deviation) difference between the Lainhart Dam water levels and those recorded downstream at each transect location (in feet NGVD).

Transect Name	Transect 1	Transect 2	Transect 4	Transect 5
Station Id.	LOX.R1_G	LOX.R2_G	LOX.R3_G	LOX.R4_G
Mean (STD)	0.78 (0.28)	3.04 (0.37)	6.12 (0.42)	8.33 (0.38)

Based on these data, a minimum flow of 35 cfs recorded at the Lainhart Dam would inundate more than 50% of the floodplain on average (**Table 41)**. In contrast, nearly 95% of the floodplain is inundated under a flow regime of 300 cfs, while flows of less than 10 cfs would be required to allow surface water to fully receded from the floodplain (**Table 41).**

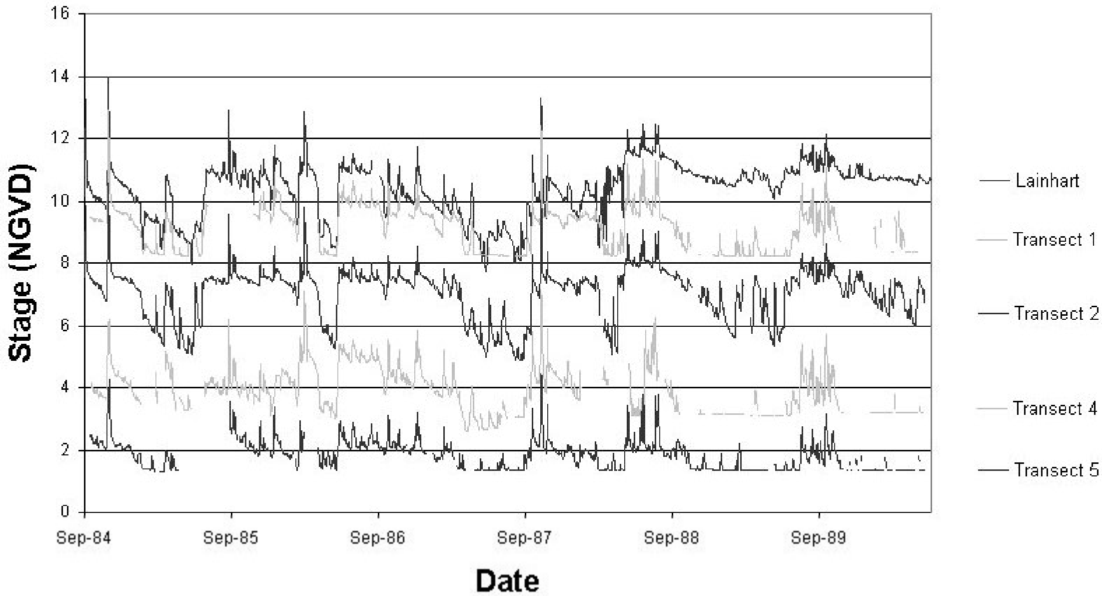


Figure 32. Daily Stage hydrographs for the four transects sites and Lainhart Dam (1984-1990)

Table 41 . Percent of floodplain inundation related to flows over Lainhart Dam (excluding uplands and river channel).

	Lainhart Dam Flows (cubic feet/second)								
	10cfs	25cfs	35 cfs	48cfs	65cfs	75cfs	100cfs	200cfs	300cfs
Transect 1	14**	44	61	61	64	64	69	78	86
Transect 2*	0	7	16	40	49	53	74	86	91
Transect 4	25	58	75	93	95	95	100	100	100
Transect 5	5	43	57	71	81	83	93	98	100
Average (Transects 1, 4, & 5)	15	48	64	75	80	81	87	92	95
Average (all transects)	11	38	52	66	72	74	84	91	94

*= This transect is located just downstream of the Masten Dam and is heavily influenced by this structure
** = Percent of transect inundated at a given Lainhart Dam flow

Providing a dry season flow regime that would inundate more than 50% of the floodplain would provide protection from the effects of over-drainage. In addition, water levels maintained within this range would also (a) provide aquatic refugia for aquatic invertebrates, amphibians and fish species to survive during dry periods, (b) reduce the possibility for invasion by Melaleuca, Brazilian pepper and Old World climbing fern, and (c) reduce the frequency of severe fires that could impact the remaining floodplain swamp forest. Overall, these results indicate that a minimum flow regime of 35 cfs would have no adverse impact on the upstream floodplain swamp. For more details regarding these analyses are in **Appendix N**.

Effects of the Proposed MFL on Navigation and Recreation

When flows over the Lainhart Dam are less than 35 cfs, navigation and recreational uses of the Northwest Fork become impaired. Access to the river by recreational boaters, fishermen, canoeists and kayakers becomes limited and at times, is restricted. Due to many fallen trees, littoral areas and shoals that are exposed or contain only a few inches of water, thereby creating conditions that limit navigation and recreational use of the resource.